Appendix G

Heavy-Duty Inspection and Maintenance Program Pilot Report

Proposed Heavy-Duty Inspection and Maintenance Regulation

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Executive Summary

Since the passage of Senate Bill (SB) 210 in 2019, the California Air Resources Board (CARB or Board), in collaboration with other state agencies and participating stakeholders, vendors, and contractors, developed and implemented a pilot program demonstrating potential technologies and methods for use in California's future heavy-duty inspection and maintenance (HD I/M) program. Studies focused not only on potential vehicle compliance test mechanisms, but also potential enforcement screening and vehicle identification methods that could be incorporated into the program to effectively bring vehicles into the HD I/M program. Beyond simply testing each technology, CARB assessed how various technologies could potentially be integrated together to improve the overall effectiveness of the future HD I/M program.

Under a CARB-funded research contract (CARB contract 15RD022), the University of California, Riverside's Center for Environmental Research and Technology (CE-CERT) performed preliminary HD I/M research to assess potential program structures and make an overall recommendation for a future HD I/M program. To do this, CE-CERT performed a literature review of different inspection and maintenance programs around the globe and performed a small-scale vehicle repair study to assess the effectiveness of different testing options. Based on repair results from the study, CE-CERT concluded that a future HD I/M program could result in substantial oxides of nitrogen (NOx) emission reductions, reducing heavy-duty vehicle (HDV) in-use emissions by about 50 to 75 percent from current baselines. Furthermore, based on the literature search and testing that was conducted as part of the study, CE-CERT recommended an on-board diagnostic (OBD)-based program incorporating a remote sensing screening element as the most cost-effective structure for designing a future HD I/M program. CARB used these preliminary results as a springboard to engage stakeholders, vendors, and other state agencies in discussions related to the overall structure and design of a future HD I/M program and the development of a pilot program to further assess potential feasibility.

As part of the pilot efforts, CARB staff coordinated with Eastern Research Group (ERG) and participating vendors to conduct testing focused on the potential incorporation of OBD testing into a future HD I/M program. Prototype OBD testing devices provided by participating vendors were used in combination with commercially available products to gather OBD data from HD vehicles and assess potential compliance with a future HD I/M program. The pilot efforts demonstrated that OBD collection could be used as an effective vehicle compliance test and that the OBD data fields CARB staff has proposed to collect as part of the upcoming HD I/M regulatory proposal would be feasible for testing devices to collect. The success of this testing assessment effort and the use of these piloted devices provide strong indications that vendors would be able to develop devices that meet the data collection requirements of a future HD I/M program in order to assess program compliance. Furthermore, ERG also coordinated with HDV repair shops to assess potential repair costs that could be associated with potential emissions control-related repairs in the future HD I/M program. ERG found average repair costs for OBD compliance issues to average slightly under $2,000 per repair. This cost data is used to help assess the economic impacts and cost-effectiveness of the future HD I/M program.

CARB also coordinated with the University of California, Irvine (UCI) Institute of Transportation Studies via an interagency agreement to conduct a pilot study relevant to the future use of Automated License Plate Recognition (ALPR) cameras and their potential use to monitor vehicle traffic into and out of the state. ALPR cameras were installed at multiple locations in Southern California to collect vehicle license plate information and assess the potential to use this technology as a method to help monitor for compliance with a future HD I/M program. This field pilot successfully tested that vehicle license plate data needed to cross-reference with vehicle compliance status to enforce on future non-compliant vehicles can be collected. Furthermore, the field testing provided valuable lessons to help optimize vehicle information collection rates for the future HD I/M program through improvements in camera positioning and software.

As part of efforts to improve enforcement of the future HD I/M program, CARB staff have internally been developing the **Portable Emissions Acquisitions System (**PEAQS) in association with ALPR systems over the past several years. These vehicle monitoring systems are envisioned to be used as potential screening tools for enforcement-related activities in the future HD I/M program. As part of these pilot efforts, CARB staff performed testing to demonstrate the capabilities of PEAQS and ALPR installments, which could be set up at various locations throughout the state to establish a statewide screening network for vehicles operating with high emissions. These pilot efforts tested the PEAQS systems in the field and assessed the feasibility of an unmanned permanently installed PEAQS network, along with manned mobile PEAQS units that can be moved to various locations throughout the state based on program needs. These pilot efforts helped staff uncover many ways to improve on the current PEAQS system to help ensure a robust design and application upon the implementation of the proposed HD I/M program. As examples, improvements made based on the results of these field testing efforts led to improvements in the durability of the overall system, improved detection of Transport Refrigeration Unit (TRU) activity, and an increase in vehicle capture rates. Overall, the pilot efforts demonstrated that PEAQS systems could effectively be installed both at unattended, semi-permanent locations and as mobile units to target potential non-compliant hot spots.

Pilot efforts also included a two-week pilot campaign in November 2020 performed in coordination with the California Department of Food and Agriculture (CDFA) and participating vendors near Mountain Pass, California. Various vehicle emissions testing systems were piloted to better understand how vehicle compliance tests such as OBD testing and opacity testing could work in collaboration with enforcement screening technologies. Multiple roadside emissions monitoring device (REMD) systems (including CARB's in-house PEAQS, as well as systems developed by two vendors, HEAT and OPUS) screened vehicles for emissions. Then, CARB staff used a subset of screened vehicles to further evaluate the systems in relation to potential vehicle compliance testing methods, e.g. OBD and opacity testing. Over ten thousand HDVs went through REMD test instrumentation, and over a hundred of these vehicles were subjected to the OBD and opacity testing over the two-week period. Results from the Mountain Pass pilot suggested that the three REMD systems can effectively be used as screening tools within the HD I/M construct. All three systems demonstrated effectiveness as stand-alone screening systems, meaning they could all be incorporated into a future HD I/M screening network. Thus, the future HD I/M program could incorporate REMDs as a screening tool. A vehicle identified by a REMD system as potentially having an emissions issue could be flagged for a follow-up compliance determination test such as an OBD test or opacity test to determine if the vehicle has a malfunctioning emissions control system and needs repair.

Another effort discussed in this report includes a one million dollar grant program conducted by CARB and the San Joaquin Valley Air District to assess the potential for a repair assistance program associated with the future HD I/M program. Approximately 150 vehicles were repaired at three repair shops in the San Joaquin Valley in the project. Although vehicles were successfully repaired, the project highlighted several challenges that would exist in setting up such a heavy-duty repair assistance program statewide. Finally, CARB undertook an internal repair study to assess the feasibility of repairing vehicles with severely malfunctioning aftertreatment. This study looked at the ability to effectively repair these vehicles, the emissions benefits that could be associated with these repairs, and the potential durability of the repairs. This was done through pre- and post-repair emissions measurements, followed by releasing these vehicles back into operation, and then procuring them again for follow-up emissions testing. This internal repair study showed that such vehicles could be repaired effectively resulting in substantial emissions benefits and durable repairs.

The table below summarizes the main conclusions of each of the studies laid out in this report. Chapter one lays out the initial background of why this report was conducted, then the subsequent chapters cover each of the studies discussed above.

STUDY (CHPT. #)	CONCLUSIONS
PRE-PILOT HD I/M STUDY (2)	• Repairs reduced NOx by 50 to over 75 percent. • Repairs cost \$250 to \$8,660; average cost was \$2,037. • Program Design Recommendation: Periodic OBD data collection w/roadside emissions monitoring. • Chassis dynamometer, Portable Emissions Measurement System (PEMS) are not recommended for statewide vehicle compliance testing.

STUDY (CHPT. #)	CONCLUSIONS
OBD TESTING (3)	• Acquisition of OBD data being considered for the I/M program with two commercially available scan devices was demonstrated. • OBD data needed as part of an HD I/M program can reliably be acquired from current testing instrumentation. • OBD scans are quick to complete with an average duration of a couple of minutes. • The future HD I/M program could use either continuously connected or non-continuously connected scan devices.
ALPR FOR OUT-OF-STATE TRUCKS ENTERING CALIFORNIA (4)	• ALPR systems successfully collected license plate data from heavy-duty trucks with capture rates of 74 to 77 percent. • Lessons learned included: Certain types of plates are more difficult to recognize than others due to differences in their reflectivity. Roadside power can be inconsistent in some locations. Certain times of day present challenges due to different light conditions. Camera positioning and software calibration are key. Collaboration with external agencies may require encroachment permits or a memorandum of understanding. Some vehicles are missing their front license plates and will therefore be missed by ALPR systems.

STUDY (CHPT. #)	CONCLUSIONS
REMDS (5)	• PEAQS units are durable and reliable for long-term permanent use. • Recent improvements to the ALPR system have increased plate capture rate from 80 to above 90 percent. • New methods are needed that can distinguish TRU and tailpipe exhaust. • Future updates to PEAQS units based on lessons learned from these pilot efforts will improve detection capabilities. • Over 10,000 vehicle emissions data points were collected from vehicles travelling through participating REMD systems. • Three emissions monitoring systems were demonstrated as potential screening tools. • Over 100 OBD and opacity tests were obtained from vehicles participating in the campaign. • NOx emitted by HDVs measured on more than one day was similar. • Collected OBD data suggests vehicles operating with illuminated MILs have been travelling for a significant amount of time in a malmaintained state (over 100 hours of engine run-time, and over 5,000 kilometers traveled).
REPAIR ASSISTANCE (6)	• A $1 million program in the San Joaquin Valley performed 156 repairs. • To scale up to the state level, contracting difficulties would need to be overcome, and a streamlined system to determine eligibility would be needed. • It is unclear if such a program would be a good use of State funds given the Governor’s direction to transform the state including trucking to zero-emission technologies
REPAIR DURABILITY (7)	• A CARB program repaired seven HDVs, reducing PM and/or NOx emissions by at least 55 percent. • HDVs with severely malfunctioning aftertreatment were repaired and their emissions were reduced dramatically. • Three HDVs were recaptured one month to three years after initial repairs; these repairs were found to be durable.

All in all, the efforts described herein helped demonstrate and fine-tune the use of technologies that may be used within the California HD I/M program. Furthermore, these efforts helped confirm the feasibility of rolling out an OBD based HD I/M program with a complementary REMD enforcement screening component. Further coordination and technological development will continue to ensure an effective rollout of the program.

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List of Acronyms and Other Abbreviations

ALPR	Automated License Plate Recognition
APCD	Air Pollution Control District
BAR	Bureau of Automotive Repair
BC	Black Carbon
CARB	California Air Resources Board
CE-CERT	Center for Environmental Research and Technology
CDFA	California Department of Food and Agriculture
CHP	California Highway Patrol
DEF	Diesel Exhaust Fluid
DM	Diagnostic Message
DMV	Department of Motor Vehicles
DPF	Diesel Particulate Filter
DTC	Diagnostic Trouble Code
EF	Emission Factor
EGR	Exhaust Gas Recirculation
ELD	Electronic Logging Device
GVWR	Gross Vehicle Weight Rating
HD I/M	Heavy-Duty Inspection and Maintenance
HDV	Heavy-Duty Vehicle
HDVIP	Heavy-Duty Vehicle Inspection Program
HDVRP	Heavy-Duty Vehicle Repair Program
IR	Infrared
MIL	Malfunction Indicator Lamp
MY	Model Year
NOx	$NO + NO_2$ (oxides of nitrogen)
OBD	On-Board Diagnostics
OEM	Original Equipment Manufacturer
PEAQS	Portable Emissions AcQuisition System
PEMS	Portable Emissions Measurement System
PGN	Parameter Group Number
PID	Parameter ID
PM	Particulate Matter
PSIP	Periodic Smoke Inspection Program
QA/QC	Quality Assurance / Quality Control
REMES	Roadside Emissions Monitoring and Enforcement System
REMD	Roadside Emissions Measurement Device
ROBD	Remote On-Board Diagnostic
RSD	Remote Sensing Device
SAE	Society of Automotive Engineers
SB 210	Senate Bill 210
SCR	Selective Catalytic Reduction
SPN	Suspect Parameter Number

TM&M	Tampering, Malfunction, & Mal-maintenance
TRU	Transport Refrigeration Unit
UCI	University of California, Irvine
UV	Ultraviolet
VDECS	Verified Diesel Emissions Control Strategy
VIN	Vehicle Identification Number

Chapter 1 Introduction and Background

California's Air Quality Issues and Need for Emissions Reductions

HDVs continue to be major contributors to statewide mobile air pollution even though this sector makes up only a small portion of California's total on-road vehicle fleet. In 2020, these vehicles emitted approximately 52 percent of the statewide on-road mobile source NOx emissions and about 54 percent of the statewide on-road mobile source fine particulate matter ($PM_{2.5}$) emissions (CARB, 2021a). HDVs' PM and NOx emissions impose a damaging effect on human health and the environment. In 1998, CARB identified PM from diesel-fueled engines as a carcinogenic toxic air contaminant due to its contribution to increased mortality, cancer risk, and serious illness (CARB, 2021b). NOx is a precursor of ozone formation and several other toxic air contaminants, including PM. Exposure to PM and ozone can lead to serious adverse health effects such as asthma, cardiopulmonary and respiratory diseases, and premature deaths. The majority of densely populated areas in California, such as the South Coast and San Joaquin Valley air basins, are still not in attainment with the federal ozone and $PM_{2.5}$ standards (US EPA, 2021). Thus, it is critical for CARB and the State of California to continue to work on programs that substantially reduce emissions from the vehicle sector to reduce the impact of these harmful pollutants on the state's constituents.

Overall attainment strategies for meeting federal air quality attainment standards are defined through the State Implementation Plan (SIP) process, which considers emission reduction measures from all pollution sources, including mobile sources. Through SIPs for the South Coast and San Joaquin Valley regions, CARB and the respective air districts have committed to regional NOx and PM emissions reductions from all sectors, including emissions reductions from the HDV sector. The development of an improved HD I/M program to further reduce in-use HDV emissions is expected to play a critical role in helping California meet near-term federal attainment NOx and PM standards in the South Coast and San Joaquin Valley regions, as well as in achieving overall statewide clean air goals outlined in CARB's Mobile Source Strategy (CARB, 2020d). Specifically, a revamped HD I/M program is critical for further progressing to meet the federal 8-hour ozone attainment deadlines in the South Coast Air basin in 2023 and 2031, and to achieve PM reductions for the 2024 federal attainment deadline and $PM_{2.5}$ reductions for 2025 federal attainment deadlines in the San Joaquin Valley region.

Overview of California's Current Heavy-Duty Vehicle Inspection Programs

In an effort to limit excess emissions from in-use HDVs, CARB currently implements two in-use vehicle inspection programs, the Heavy-Duty Vehicle Inspection Program (HDVIP) and the Periodic Smoke Inspection Program (PSIP). In the early 1990s, CARB first adopted the roadside program, HDVIP, that allows CARB staff to inspect heavy-duty trucks and buses operating in California for excessive smoke, tampering, and engine certification label (ECL) compliance. These CARB inspections are typically performed at border crossings, California Highway Patrol (CHP) Commercial Vehicle Enforcement Facilities (more commonly known as "weigh stations"), fleet facilities, and other randomly selected roadside locations. Vehicle owners found in violation are subject to monetary penalties and required to provide proof of correction to clear violations.

To complement the roadside HDVIP, CARB also adopted the Periodic Smoke Inspection Program (PSIP). In PSIP, California-based fleet owners of two or more heavy-duty diesel vehicles are required to perform annual smoke opacity tests following the Society of Automotive Engineers (SAE) International J1667 testing procedure (SAE, 1996) and adhere to other program requirements, such as recordkeeping. CARB staff are also authorized to randomly audits fleets, review maintenance and inspection records, and test a representative sample of vehicles to enforce the PSIP regulation.

Upon initial implementation in the early 1990s, the smoke opacity limits for both HDVIP and PSIP were set at 40 percent for 1991 and newer MY heavy-duty diesel engines and 55 percent for pre-1991 MY heavy-duty diesel engines. These opacity limits remained unchanged until 2018 when the Board approved more stringent smoke opacity limits (CARB, 2018), lowering the opacity limits to 5 percent for DPF equipped vehicles. The 2018 regulatory amendments to the HDVIP and PSIP reflect improvements in engine design and the evolution of PM exhaust emission control technologies and diesel fuel composition that have occurred since the inception of HDVIP and PSIP. Beginning with the 2007 model year (MY), new heavy-duty diesel engines were required to meet a PM engine standard of 0.01 grams per brake horsepower-hour (g/bhp-hr), which resulted in the widespread use of diesel particulate filters (DPFs) to meet this new engine standard. Additionally, CARB in-use rules such as the Truck and Bus rule required the installation of CARB-verified aftermarket DPFs for many HDV equipped with 2006 and older MY engines.

Need for Further Program Improvements

The implementation of the 2018 PSIP and HDVIP amendments have improved the ability to identify vehicles with broken DPFs. However, because these programs rely on smoke opacity inspections, they are limited to controlling PM emissions, even though near-term NOx emissions reductions throughout California are critical to achieving our clean air goals, protecting public health, and meeting federal attainment standards.

The current new engine emission standards in place since the 2010 (MY) require modern diesel engines to use NOx aftertreatment systems, such as selective catalytic reduction (SCR) (CARB, 2019a). However, the current smoke opacity test method does not measure NOx and hence does not verify whether emissions control systems like the SCR are in good condition.

Furthermore, advanced OBD systems became implemented with the 2013 (MY) for diesel-fueled heavy-duty engines and are specifically designed for monitoring the complete emissions control system of in-use vehicles (CARB, 2021e). OBD works by identifying malfunctions in emissions-related components, illuminating the malfunction indicator light (MIL), and storing fault codes to assist repair technicians with identifying and repairing broken emissions control components and systems. As the current HDVIP and PSIP programs rely mainly on the smoke opacity test for emissions-related diagnosis, the programs are only able to identify and ensure repairs on a subset of emissions control-related issues on HD vehicles, leaving many vehicle emissions issues unchecked resulting in the potential for excess emissions. As discussed later in this report, studies suggest that about 12 percent of vehicles in California are operating with an illuminated MIL.

In addition, enforcement enhancements relative to CARB's current HDVIP/PSIP regulations would help ensure more vehicles readily meet program requirements. The HDVIP program relies on roadside inspections of vehicles operating in California; however, due to limited CARB enforcement resources, HDVIP roadside inspections are only performed on about two percent of the total vehicle population operating on California roads per year. The PSIP program relies on CARB enforcement teams auditing fleets with annual smoke inspections; however, limited enforcement resources also hinder CARB's ability to effectively perform enough audits to ensure all fleets are meeting the PSIP requirements. This, in combination with the reliance on smoke opacity tests for vehicles with more advanced emissions detection systems, has resulted in more vehicles operating in California with excessive emissions than desired.

Senate Bill 210

Recognizing that a revamped and robust HD I/M program could provide significant and critically needed NOx and PM reductions, Senator Connie Leyva introduced SB 210 (Leyva; Chapter 298, Statutes of 2019) to direct CARB, in consultation with its partner State agencies, to develop a new, comprehensive HD I/M program applicable to non-gasoline HDVs operating in California with a gross vehicle weight rating (GVWR) above 14,000 pounds. SB 210 was signed into law by Governor Newsom on September 20, 2019. SB 210 specifically authorizes key general HD I/M program elements, including:

- HD I/M Test procedures that include, but are not limited to, the use of OBD data;
- Requirements for California-registered vehicles to pass the HD I/M test procedures, to be defined in the regulation, in order to register with the Department of Motor Vehicles (DMV) and operate in California;
- Requirements for all HDVs[1] to demonstrate compliance with the HD I/M requirements, pay a compliance fee, and obtain a valid compliance certificate to legally operate in California; and
- Statutory authority for CHP to cite vehicle owners for:
    - Invalid compliance certificate or lack of a valid compliance certificate;
    - Operating with an illuminated MIL; and
    - Operating with visible smoke opacity.

In doing so, SB 210 provides the opportunity to gain significant emission reductions beyond CARB's current vehicle inspection programs.

SB 210 also includes requirements specific to conducting HD I/M pilot program activities ahead of the Board's consideration of the proposed HD I/M regulation and its implementation. The bill states that CARB must conduct a pilot program in consultation with other state agencies to develop and demonstrate technologies that show potential for

[1] As per SB 210 requirements, this includes nearly all non-gasoline vehicles over 14,000 pounds GVWR, including out-of-state and out-of-country vehicles.

readily bringing vehicles into the program. SB210 requires the findings of the pilot program to be posted on CARB's internet website.

Public Engagement for SB 210 Pilot Program Activities

As specified in SB 210, the pilot program should "develop and demonstrate technologies that show potential for readily bringing vehicles into the program." SB210 directs CARB to work in consultation with State agency partners and stakeholders as part of a public process. In 2019, CARB staff conducted an initial public workshop to discuss the need for an HD I/M program and to solicit other ideas for reducing emissions from in-use HDVs operating in California. Three subsequent workgroup meetings were conducted to further explore concepts for reducing in-use HDV emissions. After the passage of SB 210 in late 2019, CARB staff conducted four public workshops and six public workgroup meetings. These workshops and meetings focused on developing an effective HD I/M program structure and creating a pilot program to test compliance and enforcement strategies that could be incorporated into HD I/M. The public workshops were aimed at a broad cross-section of interested stakeholders and members of the public. They included representatives of heavy-duty fleets, trucking associations, engine/vehicle/device manufacturers, non-governmental organizations, and vehicle inspection and maintenance administrators in other states and countries. These meetings helped staff discuss and exchange ideas with interested stakeholders regarding the potential design of the HD I/M program and to delve into more technical details of specific program elements and potential pilot program activities.

CARB staff has also frequently met individually with interested stakeholders and organizations to further discuss the SB 210 pilot program development and overall program design. These stakeholders included representatives of trucking associations, agricultural trade associations, environmental groups, telematics service providers, OBD device vendors, and vehicle inspection and maintenance program representations from other states, among others. As directed by SB 210, CARB staff also regularly coordinated with the Bureau of Automotive Repair (BAR), DMV CHP, Department of Transportation (CalTrans), and the California Department of Food and Agriculture (CDFA) on the development of the HD I/M program and related pilot program activities, and will continue to do so when HD I/M program implementation begins.

Dates when public workshops and workgroup meetings were held are shown below (Table 1-1Table 1-2). Areas of expertise of State agency partners where coordination between CARB and the other agencies was focused are also summarized below in Table 1-3. Workshops and workgroup meetings shown in bold italicized text were specifically focused on SB 210 pilot program development and progress updates. Starting with the July 9, 2020, workgroup meeting, all workshops, workgroup meetings, and meetings with individual stakeholders, including State agency partners, were conducted via teleconference and/or webinar in accordance with Governor Newsom's Executive Orders *N-29-20* and *N-33-20*, as well as in accordance with recommendations from the California Department of Public Health.

Table 1-1. 2019 HD I/M Public Workshops and Workgroup Meetings (before the passage of SB 210).

DATE	EVENT
FEBRUARY 11, 2019	Workshop
MAY 14, 2019	Workgroup Meeting
JULY 16, 2019	Workgroup Meeting
NOVEMBER 8, 2019	Workgroup Meeting

Table 1-2. 2020 and 2021 HD I/M Public Workshops and Workgroup Meetings (after the passage of SB 210). Four public meetings focused on the pilot activities, highlighted in bold text.

DATE	EVENT
JANUARY 29, 2020	***Workshop to discuss SB 210 pilot program concepts and solicit additional stakeholder concepts***
FEBRUARY 19, 2020	***Workgroup meeting to continue potential pilot program concepts***
JULY 9, 2020	Workgroup Meeting
AUGUST 12, 2020	Workshop
NOVEMBER 16, 2020	***Workgroup meeting to discuss pilot program activities and progress updates***
DECEMBER 17, 2020	Workgroup Meeting
FEBRUARY 22, 2021	Workgroup Meeting

MARCH 29, 2021	Workgroup Meeting
MAY 27, 2021	Workshop
AUGUST 3, 2021	***Workshop to discuss SB 210 pilot program efforts and revised draft regulatory text***

Table 1-3. Coordination with State Agency Partners on SB 210 Pilot Activities.

STATE AGENCY	COORDINATION ROLE
BUREAU OF AUTOMOTIVE REPAIR	Expert consultant on I/M implementation, OBD data collection devices, and OBD data collection device certification
DEPARTMENT OF MOTOR VEHICLES	Vehicle data exchange process and California vehicle registration hold process of HD I/M non-compliant vehicles
CALIFORNIA HIGHWAY PATROL	Enforcement strategies coordination, installation of REMD at CHP sites
CALIFORNIA DEPARTMENT OF TRANSPORTATION	Assistance with site determination and installation of emissions monitoring equipment and ALPR camera, roadside siting and permitting
CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE	Assistance and coordination with equipment installation at CDFA agricultural inspection stations for pilot activities and future program efforts

SB 210 Pilot Effort

CARB staff and stakeholders used the guiding framework from SB 210 to develop the HD I/M pilot program. The pilot program encompassed multiple activities to holistically evaluate strategies and technologies for potential use in the HD I/M program. Strategies and technologies were aimed at enhancing vehicle participation in the program, assisting overall compliance efforts, and establishing effective enforcement mechanisms.

As meetings were held to discuss the potential design of the pilot program, some stakeholders suggested implementing the fully proposed HD I/M program for a short time, potentially in just one region of the state, as the pilot program itself. However, after further discussions on this topic, for the three reasons described further below, staff concluded such a full program pilot would not be consistent with the SB210 legislative intent or feasible.[2]

First, SB210 requires the pilot work to be completed prior to staff taking a regulatory proposal to their Board for consideration. The full HD I/M program will require a database system that receives vehicle data and test results and issues certificates of compliance and is connected with DMV registration. That database system cannot be fully completed until staff proposes and CARB approves the regulation, staff completes the State of California Project Approval Lifecycle process, and CARB's contractor builds, deploys the database system, and then connects it with DMV's vehicle registration system. Due to the need to complete the aforementioned steps, it would not be possible to perform a full program pilot and still meet the SB210 requirement for the pilot to be complete before the program is proposed to the Board.

Second, SB210 explicitly mentions testing "technologies that show potential," indicating the authors of the language recognized the value of testing individual technologies that could be included as part of a future program, rather than building out the entire program before performing a pilot of the whole. SB210 states: "This bill would require the state board, in consultation with the bureau and other specified entities, to implement a pilot program that develops and demonstrates technologies that show potential for readily bringing heavy-duty vehicles into an inspection and maintenance program…" In fact, when SB210 was being considered by the Legislature, the bill sponsor, Senator Connie Leyva, shared handouts with legislative staff specifically describing the pilot program as consisting of demonstrations of individual test devices that collect and submit OBD data (Office of Senator Connie Leyva, 2019).

Third, on January 26, 2021, Senator Connie Leyva sent CARB a letter expressing concerns with the program not being implemented until 2023 (Leyva, 2021). However, if Senator Leyva had envisioned the hiring of an implementation contractor and full database development prior to the pilot work, all before Board consideration of the regulation, she never would have sent a letter urging implementation in 2023. Under such a sequence of steps, the pilot program would realistically not be completed prior to 2023, pushing Board

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[2] "No later than two years after the completion of the pilot program required by Section 44156 and to the extent authorized by federal law, the state board, in consultation with the bureau and the Department of Motor Vehicles, shall adopt and implement a regulation for a Heavy-Duty Vehicle Inspection and Maintenance Program…"

consideration to 2024, and program implementation out no earlier until 2025. Considering the urgency that Senator Leyva expressed regarding the timing of this HD I/M program and the timing of upcoming federal attainment deadlines, it is clear that Senator Leyva envisioned piloting of individual technologies which could be completed on a more rapid timescale.

Based on the rationale described above, CARB staff designed and implemented a pilot program that demonstrated technologies both for compliance determination and for catching vehicles trying to skirt the requirements of the program. The latter enforcement-related technologies are expected to enhance compliance rates with the program, thus bringing more vehicles into the program. Knowing that testing beyond this pilot program is important to ensure a smooth and robust rollout of the HD I/M program, CARB staff plans to further test each program component prior to rolling out each implementation phase of the proposed HD I/M program.

Performing the pilot program prior to officially proposing and implementing the HD I/M program helps to ensure the official program incorporates lessons learned from the pilot into the final design. It will also help ensure HD I/M is rolled out smoothly for stakeholders, and that the program design achieves maximum emissions reductions from the HD vehicle sector. For the purposes of this report and ease of reading, the pilot program description is broken up into separate chapters focusing on various technologies with the potential to bring vehicles into the program and ensure they are compliant with program requirements. This report breaks down the overall pilot program into the following chapters:

- **Chapter 2: Establishing the Feasibility of an HD I/M Program in California**
- **Chapter 3: OBD Testing Assessment**
- Chapter 4: **Monitoring Vehicles Coming Into California Using Automated License Plate Recognition (ALPR) Cameras**
- **Chapter 5: Remote Emissions Monitoring Devices to Support HD I/M**
- **Chapter 6: San Joaquin Valley Pilot Repair Assistance Effort**
- **Chapter 7: CARB In-House Heavy-Duty Vehicle Repair Durability Study**
- **Supplemental Chapter A: Final Report, Heavy-duty On-Road Vehicle Inspection and Maintenance Program, CARB Contract No. 15RD022**
- **Supplemental Chapter B: Final Report, Heavy-Duty On-Board Diagnostic Data Collection Demonstration and Repair Data Collection Study, CARB Contract No. 18MSC001**

- **Supplemental Chapter C: Heavy-Duty Vehicle Repair Program Pilot Project, Final Report**
- **Supplemental Chapter D: Additional Information on CARB Repair Durability Study**

Chapter 2 focuses on HD I/M development efforts that were undertaken prior to the official SB 210 HD I/M pilot effort. Chapters 3 through 5 focus on specific activities done as part of the SB210 pilot. Chapters 6 and 7, although not part of the official SB210 pilot effort, are included in this report for completeness as the efforts related to the repair assistance studies and repairs are relevant to the development of the HD I/M program as a whole.

Chapter 2 Establishing the Technical Feasibility of an HD I/M Program in California

Recognizing the potential need for a new, comprehensive inspection and maintenance program for HDVs operating in California, CARB dedicated research funding to evaluate the technical feasibility of such a program and whether significant emission reductions, particularly NOx reductions, could be achieved to further California's progress in attaining federal air quality standards and CARB's overall clean air, sustainable freight, and climate goals. CARB ultimately awarded a contract to CE-CERT at the University of California at Riverside. This CE-CERT study, published in January 2019, assessed various HDV test methods and laid the foundation for further HD I/M-related studies and technology demonstrations conducted as part of the SB 210 pilot program activities. Here we summarize the project at a high level and highlight the key findings that helped lay the foundation for initial program design and pilot discussions with stakeholders. Full details of this research effort are included in the final CE-CERT report incorporated into this pilot report as Supplemental Chapter A.

Study Objectives and Methodology

CE-CERT study developed, evaluated, and assessed compliance testing options for a more comprehensive HD I/M program for vehicles over 14,000 pounds GVWR. Furthermore, recommendations for the potential design and implementation of a full-scale HD I/M program were made based on the results of the study. CE-CERT's efforts included a literature review of potential inspection and maintenance test procedures that could be incorporated into an HD I/M program, and implementation of a small-scale research prototype to assess potential feasibility in a future HD I/M program.

Based on the literature review, the study determined that the following potential methodologies and emissions testing instrumentation would be evaluated in the small-scale research prototype:

- Repair grade chassis dynamometer with NOx and PM I/M grade emissions analyzers;
- Mini-portable emissions measurement systems (PEMS), called mini-PEMS (sensor-based and solid particle number based);
- Remote emissions monitoring devices;
- OBD data collection; and
- Smoke opacity inspections.

The small-scale research prototype measured pre- and post-repair emissions from 50 vehicles with a variety of emissions testing instrumentation identified above, including the Hager Environmental and Atmospheric Technologies' Emissions Detecting and Reporting (EDAR) remote sensing device (RSD) and CARB's plume capture system, Portable Emissions Acquisions System (PEAQS).

CE-CERT selected candidate vehicles for evaluation in the small-scale research prototype from those arriving at two southern California repair facilities based on whether they fell into specific MY engine ranges and the type of emissions-related malfunction. The vehicle selection process looked to mimic a vehicle distribution similar to what we expect to find on California roads in the mid-2020s with probable emissions-related issues expected of such vehicles. The final selected test fleet was composed of 20 percent of vehicles with pre-OBD engines (2010 – 2012 MY engines) and 80 percent with OBD-equipped engines (2013 and newer MY engines).

CE-CERT also developed a target repair test matrix for the selected vehicles, which contained component or systems malfunctions expected to cause excessive emissions of different pollutants. The target test matrix was developed using the best available data and historical repair records obtained from participating repair shops to estimate the frequency at which identified repairs were expected to occur. This effort was coupled with estimates of the expected emissions increases from the various component or system failures, based on CARB's on-road emissions inventory model, EMFAC, at the time of the study.

Study Results and Recommendations

Based on the results of the small-scale prototype HD I/M program, CE-CERT recommended a tiered approach of testing options that could be implemented separately or in combination with each other for a cost-effective HD I/M program. CE-CERT's overarching recommendation was that the most effective HD I/M program would combine OBD data collection with roadside emissions monitoring to cross-check the test methods and validate program effectiveness. Presented below are CE-CERT's major findings and recommendations from the project:

- <u>Estimated NOx reductions:</u> Results from the small-scale prototype HD I/M program conducted in this study indicate NOx emission reductions ranging from about 50 percent to over 75 percent could be achieved through appropriate vehicle diagnosis and repair.
- <u>Estimated repair costs:</u> Vehicle repair costs resulting from the small-scale prototype HD I/M program ranged from $250 to approximately $8,660, depending on the extent

of repairs needed. The costliest repairs were those associated with the replacement of major components, such as the DPF, SCR, turbocharger, or injector doser. Less expensive repairs included those that were sensor replacements or recalibrations. The costs associated with OBD-related repairs could span a relatively wide range, as OBD is designed to identify issues in emissions-related components before they become catastrophic failures. For vehicles with the MIL on, the average repair cost was $2,037 per vehicle. As a comparison, the estimated annual average cost of operating a heavy-duty vehicle above 14,000 lbs GVWR is about $41,000,[3] with annual costs potentially upwards of $162,000 for class 8 long haul vehicles that operate can operate 100,000 miles per year.

- Chassis dynamometer and 40 CFR 1065-compliant PEMS: The study considered chassis dynamometer and fully 40 CFR 1065-compliant PEMS testing methods for use in a statewide HD I/M program. However, these intensive test methods would require vehicles to report to a centralized location and to be taken out of service, thereby resulting in significant operational downtime for vehicle owners. Additionally, the greater capital costs associated with these test methods and the need for extensive testing networks significantly constrain their feasibility as cost-effective and unintrusive options for a statewide HD I/M program.
- OBD data collection as the primary testing option: OBD monitors all emissions critical components and related sensors while a vehicle is operating. An OBD-based test could be relatively quick and convenient for the owner/operator in comparison to other options, and the test costs and inspection time burdens to the owner can be considerably lower than chassis dynamometer or PEMS-based alternatives. The implementation of telematics could provide further benefits in terms of the ease of implementing an HD I/M program, either through kiosk systems or through cellular data transmission.
- OBD data collection coupled with roadside emissions monitoring: CE-CERT's next recommendation was to supplement OBD data collection with a roadside emissions monitoring component, using a REMD like PEAQS. These systems capture vehicle emissions as vehicles pass by the monitoring equipment to allow analyses of emissions levels generated during real-world driving conditions. Analyses of on-road emissions

[3] This is based on a per-mile cost of $1.62 for the western United States, taken from (ATRI, 2020) by the American Transportation Research Institute, and an average annual mileage accrual of 25,467 for HDVs above 14,000 GVWR. Annual mileage accrual is based on vehicle mileage accrual projections in CARB's EMFAC.

would allow CARB staff to assess how well the HD I/M program is working as a whole, and to work towards implementing program improvements, as necessary.

Study Application

CE-CERT study's recommendations served as a foundational starting point to engage stakeholders in developing an HD I/M program structure and establishing the SB 210 pilot program. Based on the outcomes of stakeholder engagement related to the development of the SB210 pilot efforts, the pilot was designed to further test and demonstrate the various elements that had strong potential to be incorporated into the future HD I/M program. Potential program elements and the interplay between elements such as OBD testing applications, remote sensing systems, and enforcement-related technologies such as license plate camera detection were further evaluated as part of this SB210 pilot.

Chapter 3 OBD Testing Assessment

Based on the success of OBD testing in light-duty vehicle I/M programs across the US, a similar OBD focused structure for the future HD I/M program was assessed as part of this pilot effort. Considering an OBD-centric I/M program has not been implemented yet in the HDV sector, a key goal of the pilot program was confirming that OBD data can reliably be collected from the HDV population and that testing devices can be adequately developed to meet the proposed data collection requirements. This chapter focuses on pilot demonstration efforts to assess the feasibility of OBD testing devices. Furthermore, this effort looks to assess the reliability of collecting the OBD data fields CARB is currently planning to collect under the proposed HD I/M regulation. This pilot effort was done in coordination with ERG, who was contracted to help support the OBD piloting efforts.

Beyond the OBD feasibility piloting efforts, OBD fault code and MIL data were collected from a sample of the HDV population to assess potential repairs that may be associated with common fault codes. This analysis was then cross-referenced with repair shop data to estimate potential costs of the associated repairs and used to assess the potential economic impacts of a future HD I/M program. Conclusions from this pilot effort indicate that the proposed HD I/M program's OBD data collection requirements are feasible and can be met by future testing devices. Additionally, OBD data and cost information collected as part of this pilot effort can be used to support economic impact assessments associated with the development of this program. Further details can be found in Supplemental Chapter B, the final report associated with the ERG contract with CARB.

OBD Data Collection Feasibility Demonstration

The OBD demonstration effort included voluntary participation from interested fleets. Testing device vendors either developed prototype testing devices in an effort to meet the proposed OBD data collection requirements or provided currently available testing devices that already have such capabilities. CARB and ERG worked with participating vendors, test organizations, and fleets to demonstrate the testing technology and assess the level of effort and time it may take to perform such OBD data collection efforts. In addition to OBD testing efforts, an HD I/M survey was conducted on heavy-duty fleets to gather information regarding heavy-duty industry preferences related to an OBD-based HD I/M program. The demonstration study findings helped evaluate the scalability of OBD testing and OBD data transmission methods that could be used for the proposed OBD testing requirements in the future statewide HD I/M program.

OBD Data Collection Demonstration

OBD Data Collection Tools

Participating vendors included Drew Technologies and HEM Data Corporation. Figure 3-1 shows the tested Drew Technologies' DrewLinQ device. The DrewLinQ device is a commercially available vehicle diagnostic adaptor that can be used to connect the vehicle's diagnostic port to data collection or diagnostic software. To support the OBD data collection demonstration, Drew Technologies developed a software application prototype to allow the DrewLinQ device to collect OBD data from HDVs through both SAE J1939 and J1979 communication protocols. Drew Technologies also updated the device to allow it to collect all the OBD data fields specified in Tables 3-1 and 3-2, thus allowing for the collection of CARB's proposed required OBD data parameters for the future OBD-based HD I/M program. The DrewLinQ device requires the use of a personal computer (PC) or tablet computer, and online activation of the device prior to usage. Six of the devices were used for the demonstration study.

Figure 3-1. DrewLinQ OBD Data Collection Device.

In addition to the DrewLinQ device, the OBD Mini Logger and DAWN Mini Streamer provided by HEM Data Corporation, as shown in Figure 3-2, were used to collect OBD data from a subset of participating vehicles. The OBD Mini Logger is a stand-alone configurable datalogger capable of collecting and logging data for both SAE J1939 and J1979 OBD data communication protocols, and can also serve as a telematics device. The Mini Streamer provides real-time streaming of SAE J1939 and J1979 data to a PC, Android device, or iOS-based tablet (iPad as shown in Figure 3-2) for the collection of vehicle service and performance data. Similar to the DrewLinQ device, the HEM Data devices are commercially available vehicle diagnostic tools. ERG prepared a configuration file to use with the Mini Logger in the pilot program, while no updated configuration was required for the Mini Streamer.

Figure 3-2. HEM OBD Mini Logger and DAWN Mini Streamer.

Table 3-1 and Table 3-2 below summarize CARB's proposed OBD data parameters for SAE J1939 and J1979, respectively.

Table 3-1. CARB's Proposed SAE J1939 Parameters.

MESSAGE	PARAMETER GROUP NUMBER (PGN)	DESCRIPTION
DM01	65226	Active Diagnostic Trouble Codes (DTC)
DM02	65227	Previous DTCs
DM04	65229	Freeze Frame Parameters
DM05	65230	Diagnostic Readiness 1
DM06	65231	Emissions-Related Pending DTCs
DM07	58112	Command Non-continuous Test
DM12	65236	Emissions Related Active DTCs
DM19	54016	Calibration Information (Calibration Identification (Cal ID) and Calibration Verification Number (CVN))
DM20	49664	Monitor Performance Ratio
DM21	49408	Diagnostic Readiness 2
DM23	64949	Previous Emission-Related DTCs
DM24	64950	Suspect Parameter Number (SPN) Support
DM25	64951	Expanded Freeze Frame
DM26	64952	Diagnostic Readiness 3
DM27	64898	Pending DTCs
DM28	64896	Permanent DTCs
DM29	40448	Regulated DTC Counts

MESSAGE	PARAMETER GROUP NUMBER (PGN)	DESCRIPTION
DM30	41984	Scaled Test Results
DM31	41728	DTC to Lamp Association
DM32	41472	Regulated Exhaust Emission Level Exceedance
DM33	41216	Emission Increasing Auxiliary Emission Control Device (AECD) Active Time
DM34	40960	Not-to-Exceed (NTE) Status
DM56	64711	Model Year and Certification Engine Family
VI	65260	Vehicle Identification Number (VIN)
CI	65269	Engine Serial Number (SPN 588)
AC	60928	Name of controller application
ET1	65262	Engine coolant temperature
CCVS1	65265	Wheel-based vehicle speed
IC1	65270	Intake manifold #1 pressure
IC1	65270	Intake manifold #1 temperature
EEC2	61443	Accelerator pedal position 1
EEC2	61443	Engine % load at current speed
EEC1	61444	Actual engine - % torque
EEC1	61444	Engine speed
EEC1	61444	Engine torque mode

MESSAGE	PARAMETER GROUP NUMBER (PGN)	DESCRIPTION
IT6	65159	Engine actual ignition timing
AT1S	64891	Aftertreatment 1 Diesel Particulate Filter (DPF) soot load %
ESR	34560	Engine Protection Derate Override Command
CTL	52992	Engine Torque Limit Request - Maximum Continuous
EBC1	61441	Engine Derate Switch
GC2	61470	Engine Self-Induced Derate Inhibit
EOI2	61711	Engine Self-Induced Derate Load
EOI	64914	Engine Derate Request
TTI1	65204	Trip Time in Derate by Engine

Table 3-2. CARB's Proposed SAE J1979 Parameters.

Mode	**Parameter Identification (PID)**	**Description**
1	01	Malfunction Indicator Light (MIL), DTC count, status of monitors
1	02	Freeze frame DTC
1	1C	OBD Requirements to which vehicle is designed
1	21	Distance Travelled While MIL is Activated
1	30	Number of Warm-ups Since DTC Cleared

Mode	Parameter Identification (PID)	Description
1	31	Distance since diagnostic trouble codes cleared
1	41	Monitor status (trip-based)
1	4D	Minutes Run with MIL Activated
1	4E	Time Since DTCs Were Cleared
1	A6	Odometer
1	all	All other live data PIDs
2	all	Freeze Frame Data
3	n/a	Stored DTCs
6	n/a	Test Mode
7	n/a	Pending DTCs
9	01, 02	Vehicle info, VIN
9	03, 04	Vehicle info, Cal ID
9	05, 06	Vehicle info, CVN
9	09, 0A	Engine Control Unit ID
9	0D	Engine Serial Number
0A	n/a	Permanent DTCs

Field OBD Data Collection

Due to the COVID pandemic and resulting travel restrictions, field-OBD data collection in California was limited (148 HDVs). As a result, field-OBD data collection was expanded to also be performed in other states such as Arizona, Colorado, and Texas (204 HDVs). Regardless of the testing location, all vehicles were certified to CARB's OBD certification standards, thus, the change in testing venue did not impact the pilot efforts or the resultant conclusions. In total, 352 HDVs were tested, including vehicles with both the SAE J1939 and J1979 OBD communication protocols. Figure 3-3 shows the distribution of tested HDVs by vehicle make. The majority of OBD data were collected from vehicles with the SAE J1939 OBD data communication protocol (about 90 percent of tested HDVs) due to the prevalence of these vehicles compared to vehicles with the SAE J1979 OBD data communication protocol in the heavy-duty sector. Approximately 75 percent of OBD-equipped HDVs in California are certified with the SAE J1939 OBD data communication protocol.

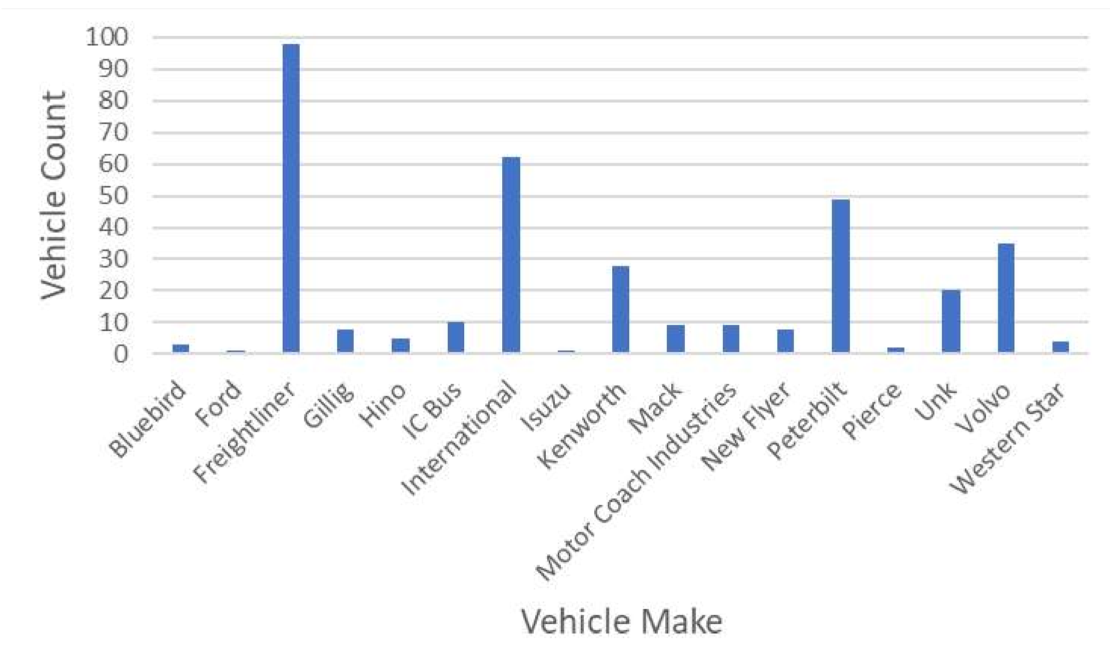


Figure 3-3. Distribution of vehicles tested by chassis original equipment manufacturer (OEM).

Figure 3-4 shows the OBD failure[4] rate distribution across the tested vehicle MYs. Although not sampled in a way to represent the distribution of the on-road fleet by age, the observed OBD failure rate trend suggested a significant percentage of newer vehicles are likely to fail an OBD test when the HD I/M program is first implemented. As shown, 12

[4] OBD failure criteria – vehicles that have MIL commanded on

percent of tested 2020 MY vehicles had MIL on. This 12 percent MIL-on rate is consistent with CARB's OBD field testing effort in 2018.[5]

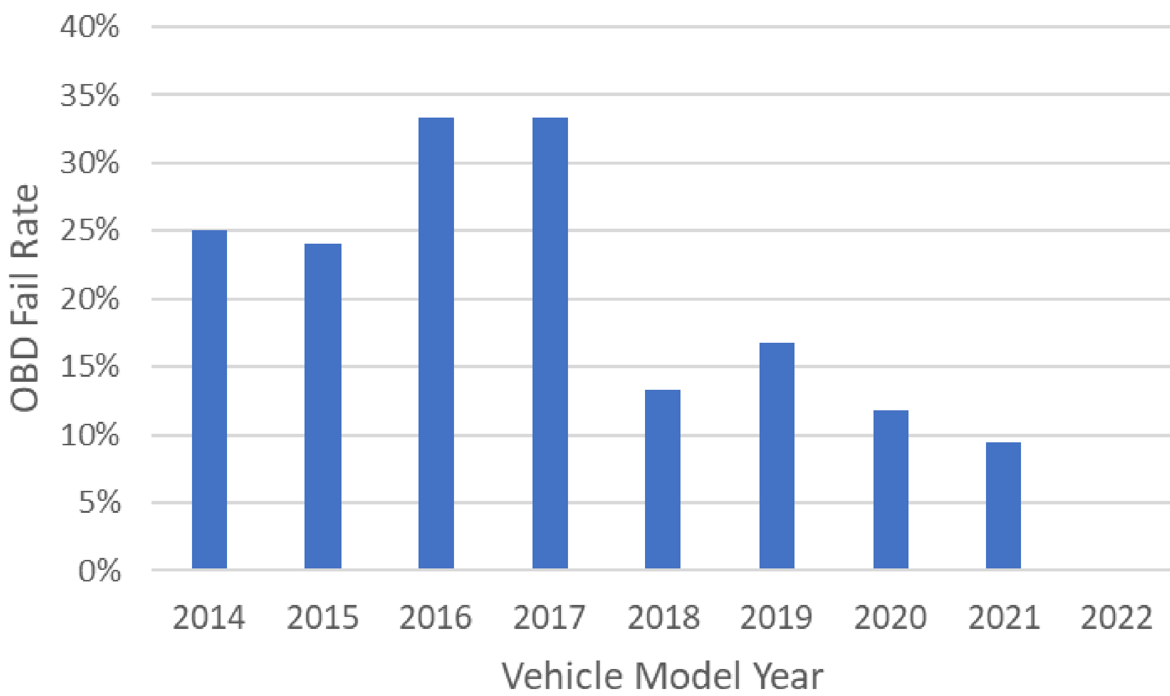


Figure 3-4. Tested Vehicle OBD Failure Rate Distribution by MY during the Field OBD-Data Collection.

Among the tested vehicles, the DrewLinQ devices were used for OBD data collection on 220 vehicles, the HEM devices were used for OBD data collection on 123 vehicles, and both DrewLinQ and HEM devices were used for OBD data collection concurrently on 9 vehicles. Albeit limited, the OBD data collected from both DrewLinQ and HEM devices were shown to be consistent with each other when tested on the same vehicles.

DrewLinQ Devices

Using the DrewLinQ devices, the average OBD testing duration for the vehicles with SAE J1939 OBD data communication protocol was about 3.5 minutes per OBD scan per vehicle; meanwhile, the average OBD testing duration for the vehicles with SAE J1979 OBD data communication protocol was significantly shorter, only 1.5 minutes.

For the vehicles tested with the SAE J1939 communication protocol, the DrewLinQ devices were able to successfully collect all CARB's proposed required SAE J1939 OBD data

[5] CARB's field OBD data collection in 2018 tested 213 randomly selected heavy-duty OBD-equipped vehicles at weight stations in Northern and Southern California.

parameters except DM30 (PGN 41984). At the time these testing and device development efforts occurred, DM30 was not included in CARB's provided data schema as part of the future HD I/M program. However, the vendor indicated that updates to the devices could be programmed in the future to collect such data as part of a full-scale HD I/M program. For vehicles equipped with the SAE J1979 communication protocol, the DrewLinQ devices were able to successfully collect all CARB's proposed required SAE J1979 OBD data parameters except the freeze frame data (Service $02). Due to time constraints on software programming related to the timing of the pilot deployments, the DrewLinQ devices were not programmed to collect freeze frame data. However, as with DM30 for the SAE J1939 protocol, the vendor indicated that device updates would be feasible to incorporate such data as part of the future full-scale program.

HEM Data Devices

As mentioned earlier, the HEM Data Mini Logger was programmed to automatically collect a pre-configured record of OBD data parameters from the vehicle OBD controllers. The HEM Data Mini Logger, as the device name implies, functions as a stand-alone data logger. As long as the device is plugged into the vehicle's OBD port, the device will continuously record and store the specified OBD data parameters from the vehicle at a specified rate. The HEM Data DAWN Mini Streamer functions in a similar manner to the DrewLinQ device to get a snapshot of the requested OBD data at the time the OBD test is performed. In general, the OBD data collection duration of the HEM Data devices was similar to the tested DrewLinQ devices.

As with the DrewLinQ, the HEM Data devices were able to collect all of CARB's proposed required SAE J1939 and J1979 OBD parameters except DM30 for SAE J1939 vehicles during the demonstration study. HEM recently reported that the HEM DAWN Mini Streamer can now acquire the DM30 parameter for SAE J1939 vehicles.

HD I/M Survey

As part of the pilot effort, a survey was conducted on heavy-duty fleets to gather information regarding industry preferences for a potential OBD-based HD I/M program. To help inform HD I/M program development, questions focused on topics related to preferences of potential OBD testing options that could be incorporated into the future program and current fleet usage of telematics and logistic services. The survey was conducted remotely via online, telephone, and email. In an effort to increase fleet participation, the survey was advertised through CARB's diesel truck information portal - The TruckStop website, as well as at CARB's One Stop training class. Furthermore, email notifications were sent out to CARB's HD I/M govdelivery subscribers and the survey was highlighted during HD I/M workgroup presentations. A summary of the results of the survey is discussed below, however, further details on the survey results and the specific questions that were asked in the survey can be found in Supplemental Chapter B as well.

In total, 37 heavy-duty fleets participated in the survey, among which 30 fleets participated via an online survey and 7 fleets participated via telephone/email survey. The number of respondents varies from question to question. Participating heavy-duty fleets in the survey vary in fleet size ranging from 1 vehicle to more than 50 vehicles with 30 percent (the highest) of the survey responses coming from single-vehicle fleets, as shown in Figure 3-5. Most of the participating fleets (63 percent) consisted mainly of in-state operation within a 100-mile radius from their domiciled base, as shown in Figure 3-6.

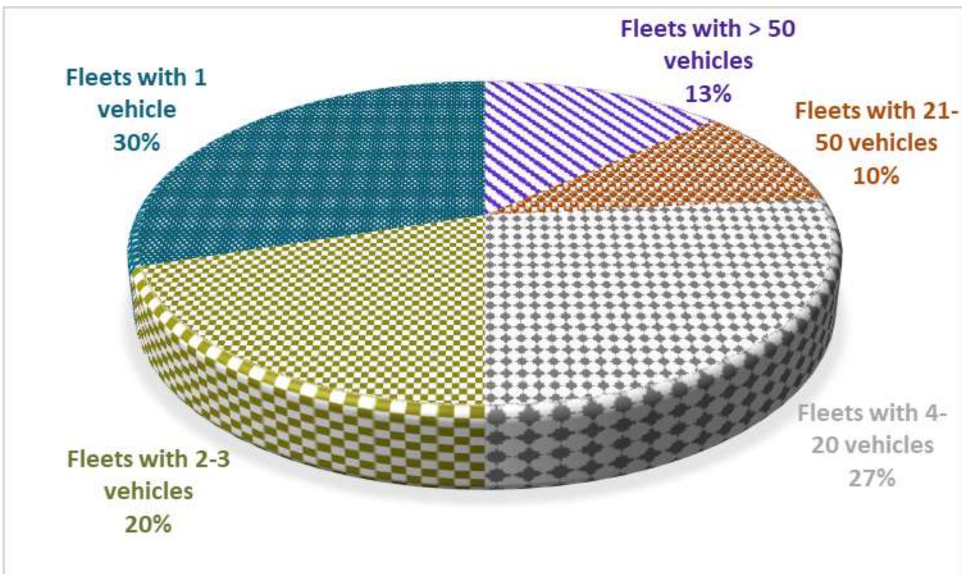


Figure 3-5. Fleet Size Distribution of Surveyed Heavy-Duty Fleets.

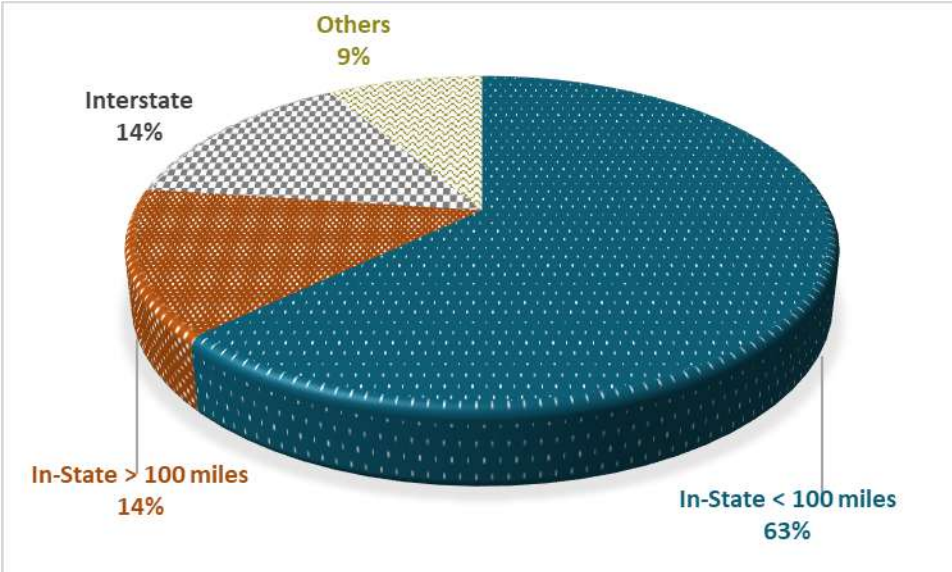


Figure 3-6. Fleet Service Type Distribution of Surveyed Heavy-Duty Fleets.

Regarding current heavy-duty fleet telematics practice, 43 percent of participating heavy-duty fleets responded they are currently using some forms of telematics services for fleet logistic management support, vehicle diagnostic and preventative maintenance support, and federal Electronic Logging Device (ELD) requirement support. Nearly all surveyed large fleets of more than 50 vehicles indicated they are using telematics (91 percent).

As part of the survey, heavy-duty fleets were queried about what OBD testing options they would prefer based on a quarterly periodic testing requirement. The OBD testing options described in the survey include:

- Fleet self-testing by kiosk: Visiting a physical testing location to self-perform required vehicle testing
- Fleet on-site testing by self or a third-party tester: Having a CARB-approved tester to perform required testing at a fleet yard or other convenient location, similar to trained testers for California's PSIP
- Telematics: Using a telematics service provider (OEM or aftermarket) to submit required compliance testing information

Forty-three percent of fleets selected the fleet on-site testing by self or a third-party tester, 37 percent of fleets selected telematics, and 20 percent of fleets selected fleet self-testing by kiosk, as shown in Figure 3-7.

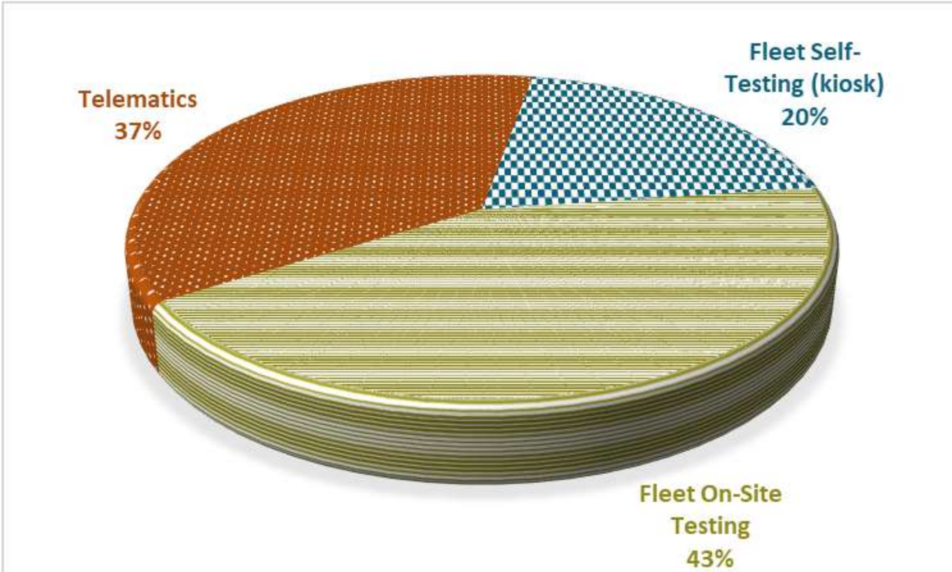


Figure 3-7. OBD Testing Preference Distribution of the Surveyed Heavy-Duty Fleets.

OBD-Related Repair Data Collection

As part of another CARB contract (ERG, 2020), ERG collected OBD fault codes for 180,000 heavy-duty OBD-equipped vehicles in the U.S. Using that data, and also fault code and repair data ERG collected in this pilot study, ERG, in coordination with sources in the HD repair industry, performed an analysis comparing OBD fault codes and associating them with related repairs and costs. The collected repair data and ERG's cost analysis supported CARB's assessment of the proposed HD I/M program repair cost analysis and potential economic impact on heavy-duty fleets due to the resulting OBD-related repairs expected to be necessary in order to comply with the upcoming HD I/M program.

From the OBD fault codes dataset, ERG identified 42 of the most commonly occurring OBD fault codes and categorized them into the following eight emissions-related groupings:

- Boost Control
- Exhaust Gas Recovery (EGR)
- Fuel System Monitoring
- NOx Sensor
- PM Filter
- PM Filter Frequent Regeneration
- Reductant Delivery
- SCR Catalyst

For each of the 42 common OBD fault codes, ERG identified the corresponding most likely repair(s) and their associated costs through commercially available repair resources and inputs from repair shops and organizations. Further details on how these determinations were made can be found in Supplemental Chapter B of this report. Table 3-3 summarizes the cost estimates for each grouping listed above by manufacturer.

Table 3-3. Average Repair Cost by Tampering, Malfunction, & Mal-maintenance (TM&M) Category by manufacturer.

TM&M CATEGORY	OEM 1	OEM 2	OEM 3	AVERAGE COSTS[6]
BOOST CONTROL	$2,623	$2,088	$2,123	**$2,278**
EGR	$1,202	$1,343	$2,092	**$1,546**
FUEL SYSTEM MONITORING	$1,598	$2,007	$1,931	**$1,848**
NOX SENSOR	$1,658	$1,849	$2,125	**$1,877**
PM FILTER	$2,606	$1,463	$2,742	**$2,305**
PM FILTER FREQUENT REGENERATION	$1,872	$1,511	$2,497	**$1,960**
REDUCTANT DELIVERY	$2,292	$1,855	$2,328	**$2,169**
SCR CATALYST	$1,490	$2,125	$1,837	**$1,817**

Table 3-4 summarizes the distribution of groupings based on their corresponding distribution of fault code counts. This was then weighted to determine an overall average repair cost for an OBD-related vehicle compliance test failure.

Table 3-4. Weighted Average OBD-Related Repair Cost per Vehicle Repair.

TM&M CATEGORY	TOTAL FAULT CODE COUNT	FAULT CODE DISTRIBUTION	REPAIR COSTS
BOOST CONTROL	5,905	10.85%	$2,278

[6] Average of all the repair costs in the corresponding TM&M category for all OEMs

TM&M CATEGORY	TOTAL FAULT CODE COUNT	FAULT CODE DISTRIBUTION	REPAIR COSTS
EGR	6,353	11.68%	$1,546
FUEL SYSTEM MONITORING	8,678	15.95%	$1,848
NOX SENSOR	8,085	14.86%	$1,877
PM FILTER	6,395	11.75%	$2,305
PM FILTER FREQUENT REGENERATION	862	1.58%	$1,960
REDUCTANT DELIVERY	10,583	19.45%	$2,169
SCR CATALYST	7,552	13.88%	$1,817
WEIGHTED AVERAGE COSTS PER VEHICLE REPAIR			**$1,977**

Based on these assumptions, an average cost of $1,977 per vehicle is estimated per repair for a potential OBD compliance failure as part of the future HD I/M program, similar to the repair costs projected from previous repair cost projections discussed previously in Chapter 2. This cost data will be used to support the economic analysis associated with the development of CARB's future HD I/M program.

Conclusions informing the structure of the future HD I/M Program

These OBD demonstration pilot efforts done in coordination with ERG successfully demonstrated that a future HD I/M program can use OBD testing as the focal point of determining vehicle compliance and that testing devices can be developed to support the program requirements. The results support the assessment that CARB's proposed HD I/M

OBD data collection requirements are feasible and that current OBD data collection technology can support CARB's proposed OBD testing requirements in a future HD I/M program. The tested DrewLinQ devices, as well as HEM Mini Logger and DAWN Mini Streamer, were shown to be able to reliably collect CARB's required OBD data parameters. These efforts also verified that the required OBD data is reliably available on HDVs and can be downloaded by testing devices when requested and that the OBD testing procedure can be performed quickly. The OBD testing duration for an OBD scan with the prototypes tested was demonstrated to be about 1.5 to 3.5 minutes on average.

Based on these results, CARB staff believes it is feasible to allow the use of two types of OBD devices as part of the future HD I/M program - non-continuously connected remote OBD and continuously connected remote OBD devices. Allowing use of both would make the program more palatable to affected truck owners, as supported by the fleet survey results suggesting that fleets prefer different testing options based on their size and type of operation. The NCC-ROBD testing device could be a single test unit with a wired connector or wireless dongle, which vehicle owners would simply plug into the vehicle OBD port to initiate OBD data submission process and unplug once the OBD data submission is complete. The CC-ROBD testing device could be integrated onto a vehicle similar to current telematics technologies. Telematics technology has been widely used in the heavy-duty transportation industry to help support fleet logistics needs, vehicle maintenance management programs, and federal electronic logging requirements (FMCSA, 2018). In this case, a similar approach could be taken to the HEM Data Mini Logger where the testing device could be programmed to automatically collect the required OBD data parameters and submit the data to CARB periodically.

Chapter 4 Monitoring Vehicles Entering California Using Automated License Plate Recognition Cameras

Introduction

Trucks registered in other states would have to comply with the HD I/M regulation if they drive on California's roadways. This represents a challenge because a hold on a DMV registration cannot necessarily be executed for vehicles registered in another state (i.e., out-of-state vehicles). Furthermore, identifying out-of-state trucks that enter California can be difficult. To help address this potential issue, staff is considering the installation of ALPR camera systems at border locations to help monitor incoming vehicle traffic. The use of ALPR camera systems potentially represents a way to enhance the identification of out-of-state heavy-duty trucks operating in California and provide an additional enforcement tool to assess vehicle compliance through the cross-reference of the collected vehicle information with a vehicle's program compliance status. If a vehicle is determined to be operating in California without demonstrating compliance with the program requirements, enforcement action can potentially be taken on the vehicle. This, in effect, could help ensure more vehicles operating in California come into compliance with the future HD I/M program.

CARB staff initiated an extramural contract to set up and pilot ALPR camera systems across Southern California. The contract, hereafter referred to as the ALPR pilot contract, has two main goals, to demonstrate the feasibility of using ALPR cameras to collect vehicle information needed to cross-reference compliance status, and provide an opportunity to learn how to refine implementation of the use of ALPR cameras for the future HD I/M program. As such, this chapter highlights some of the lessons learned from these field testing efforts regarding the use of ALPR cameras as an enforcement implementation tool in the future HD I/M program and documents the work performed under this contract related to the installation and operation of ALPR camera systems. Additionally, efforts to improve the use of ALPR cameras in coordination with REMD systems is further detailed in chapter 5 related to the in-house pilot efforts that staff has performed related to PEAQS development

As briefly mentioned above, the ALPR pilot efforts seek to investigate, design, and implement a pilot system that can be used to monitor the activity of out-of-state heavy-duty trucks entering the state through the major interstate gateways and border crossings. This was accomplished primarily by collecting license plate data using ALPR systems at multiple locations along major truck corridors in California with existing infrastructure, such as traffic cabinets, that can facilitate the installation of such technologies. These efforts gave CARB staff experience relevant to future ALPR deployments by completing the following tasks:

1. Research and identify different ALPR camera systems and work to identify the most viable product
2. Install ALPR camera systems at several sites while documenting the deployment process and logistics.
3. Monitor and analyze data collected from ALPR systems and assess their accuracy and efficacy. Metrics for system accuracy under development included correct identification of plate characters and plate State or region.
4. Understand challenges and identify methods to improve ALPR system performance, e.g., through better camera positioning, software tweaks, etc.

Project Status

ALPR systems have been installed at two locations in Southern California. Note that these locations are using ALPR systems from different manufacturers to compare capture rates, including plate character accuracy and region identification accuracy. The total number of license plates and the capture rates at these two locations are shown in Table 4-1 below. Here, capture rate is defined as a successful capture of a license plate by the ALPR system divided by the total number of vehicles passing by. These rates were determined by manual assessment of ALPR camera footage. The two camera manufacturers tested performed similarly in terms of license plate capture rate, capturing between 74 and 77 percent of the total vehicles that travelled by.

Table 4-1. Initial results from two ALPR sites.

SITE	# PLATE RECORDS	CAPTURE RATE	DATA COLLECTION PERIOD
SITE #1	12,233	77%	5/19 – 6/24/2021
SITE #2	38,133	74%	5/26 – 6/15/2021

Lessons Learned

As these ALPR cameras were installed and operated, CARB staff learned valuable lessons from the project that can help improve the technology's implementation effectiveness as part of a future HD I/M program. Overall, the systems tested were determined to successfully capture the majority of vehicles passing through, demonstrating that these systems have the potential to be used as an additional enforcement tool to help monitor a vehicle's compliance status. Additional feedback provided from this field testing is expected to lead to improvements in the future installations of ALPR systems if rolled out as part of the future HD I/M program. Some of these additional lessons learned are highlighted below:

- Certain types of plates are more difficult to recognize than others due to differences in their reflectivity (reflectivity of plates changes from one state to another).
- Roadside power can be inconsistent in some locations.
- Certain times of day present challenges (e.g., lighting). See accuracy percentages for a range of different light conditions in Table 4-2 below. Capture rates ranged from about 70 to 84 percent depending on the time of day.
- Camera positioning and software calibration are key. For example, the ALPR camera's crosshairs should be centered on the license plates.
- Some vehicles are missing their front license plates and will therefore be missed by ALPR systems. Note that only front license plates are monitored to obtain the truck chassis license plate because rear plates for HDVs are often trailer plates unrelated to the truck chassis license plate.
- CARB staff received many details related to the installation of these systems which will help identify ideal locations for future systems and improved staff's understanding of the specific steps and equipment involved in the installation process.

Table 4-2. Time-of-day accuracy of license plate readers.

LIGHT CONDITIONS	ACCURACY
DUSK	84.42%
NIGHT	77.27%
DAWN	70.00%

As ALPR setups are refined and improved beyond this HD I/M pilot, CARB's use of these systems is expected to become more accurate, thereby increasing their effective capture rates. As discussed more in Chapter 5, similar improvements in effectiveness were seen with ALPR cameras installed in collaboration with PEAQS systems as staff improved the system's setup. ALPR systems assessed as part of this pilot effort only monitored the rightmost lane. In the future, staff may try optimizing the camera position to capture vehicles in the right two lanes and, thus, capture a larger population of heavy-duty trucks operating on multi-lane highways. Such efforts could further enhance the effectiveness of ALPR systems to monitor larger populations of vehicles than if only monitoring one lane at a time. Future efforts are also planned to study the effectiveness of using ALPR systems to capture trucks with dual license plates, such as Mexican trucks near the California-Mexico border, in an effort to enhance ways to enforce a future HD I/M program at near border locations. Beyond this pilot effort itself, staff will continue to test out different ALPR camera technologies to assess if one performs significantly better than others. Staff has plans for a third camera manufacturer to be installed at another location in Southern California and will continue investigations into the technology prior to the rollout of the HD I/M program. Overall though, these field efforts demonstrated that ALPR camera technologies can effectively collect vehicle information needed to cross-reference compliance status with the HD I/M program. Future efforts will continue to further optimize the capture rates beyond the rates seen during these pilot field efforts.

Chapter 5 Remote Emissions Monitoring Devices to Support HD I/M

Introduction

As discussed in previous chapters, California's future HD I/M program is expected to require submission of OBD data to verify a vehicle's emissions control equipment is working as required. Older vehicles that do not possess OBD systems would be subject to opacity testing for compliance determination. To complement these emissions testing requirements, CARB staff is considering deploying Remote Emissions Monitoring Devices (REMDs) as enforcement screening tools to monitor emissions from HDVs operating in California. This screening could identify vehicles that have high emissions suggesting the vehicle may be operating with malfunctioning emissions control equipment. Such vehicles could then be required to submit a follow up compliance test such as an OBD scan or opacity test to ensure any issues related to the emissions control equipment have been resolved.

Methodology

REMD systems measure concentrations of various pollutants emitted from vehicles to calculate fuel-based emission factors. REMD systems measure pollutant concentrations with a variety of techniques including plume capture and optical remote sensing. Plume capture systems collect a sample of air containing HDV exhaust emissions as the vehicle passes by the device. The collected air sample is then analyzed by air monitoring equipment to quantify the mass concentrations of emissions. On the other hand, optical remote sensing techniques like UV-infrared (IR) transmittance systems emit beams of ultraviolet light and/or infrared light across or down to the surface of the road. The amount of light absorbed by specific pollutants is proportional to the mass concentration of that pollutant in a vehicle's exhaust. These mass concentrations are then used to estimate vehicle emission factors relative to CO_2 mass concentrations by stoichiometrically converting CO_2 mass concentrations to the mass of diesel fuel combusted. Emission factors are then calculated by dividing mass concentrations of pollutants by the amount of diesel fuel combusted, yielding the final emission factor (EF) form:

$$EF\ [=]\ \frac{g\ pollutant}{kg\ diesel\ burned}$$

Pollutant concentrations that exceed ambient background over relatively short timescales are assumed to be contributions of exhaust emissions from passing vehicles.

Emission factors based on the amount of diesel combusted, such as those produced by REMD, are not directly comparable to in-use standards, which are typically on a per brake-horsepower basis. However, these per kilogram of diesel combusted emission factors are useful screening metrics for current and future enforcement strategies. Vehicles identified as high-emitters could be flagged for follow-up testing via a specified vehicle compliance test, for example, an OBD test. These topics are discussed in the Lessons Learned section of this chapter.

PEAQS

Background

CARB has conducted extensive research and development to create a plume capture-based REMD called the Portable Emissions AcQuistion System or PEAQS. PEAQS units are able to quantify vehicle emissions and can be used to assist in the identification of non-compliant vehicles throughout California. While the initial purpose was to deploy systems to enforce existing in-use regulations, such as the HDVIP, the concept grew to encompass multiple systems, with the understanding that they could eventually become the foundation of a network of REMD to support the future HD I/M system. In 2018, CARB staff began deploying two types of PEAQS systems - “Unattended PEAQS” and “Mobile PEAQS”. Unattended PEAQS can be deployed for long periods of time at fixed locations, while Mobile PEAQS is attached to a mobile trailer allowing it to be deployed in locations without fixed infrastructure. In 2019, CARB staff began testing an upgraded version of these PEAQS units capable of operating in all of California’s varied environments. Upon successful piloting, the network of REMD could potentially grow to be comprised of numerous PEAQS deployed throughout the state to identify high-emitting vehicles for follow-up by CARB staff. This network of REMD may be supplemented with other REMDs developed by outside vendors. As part of this HD I/M pilot effort, several REMDs were evaluated for their potential for incorporation into an enforcement screening program, as discussed in this chapter below.

Current Activity and Pilot Efforts

Mobile PEAQS

CARB deployed Mobile PEAQS at multiple locations throughout the state in 2020 and 2021. During most Mobile PEAQS deployments, high emitting vehicles identified by PEAQS were flagged for inspection immediately after the screening. Enforcement staff then proceeded to conduct a field inspection on the vehicle, and citations were issued if violations of existing CARB programs (HDVIP, ECL, and/or transport refrigeration unit, or TRU) were found.

In 2020, the Mobile PEAQS system was deployed at eight locations, as summarized in Table 5-1 below. Subsequently, PEAQS has been deployed at two locations in 2021 (Table 5-2). The locations of these sites are mapped in Figure 5-1.

Table 5-1. Mobile PEAQS deployment dates and locations in 2020.

DATE	LOCATION TYPE	LOCATION CITY	VEHICLES SCREENED	CITATIONS ISSUED
FEBRUARY 26	CHP Scale	Camino	32	2
MARCH 3 - 4	Port of Entry/CHP	Calexico	801	8
AUGUST 18 - 19	Roadside	Sun Valley	74	N/A
SEPTEMBER 22	Roadside	Calexico	115	3
SEPTEMBER 23	Roadside	Westmorland	229	3
OCTOBER 13 -14	Roadside	Irwindale	404	4
NOVEMBER 2 - 14	CDFA	Mt. Pass	11310	N/A
NOVEMBER 17	Roadside	Fresno	207	4

At two locations ofPEAQS deployments in 2020, no inspections were conducted and no citations issued. First, the CDFA Mt. Pass deployment from November 2 – 14 was part of the pilot efforts discussed in detail later in this chapter. No citations were issued at Mt. Pass to drivers participating in the voluntary pilot. Second, CARB staff, in collaboration with Los Angeles Public Works (LAPW), also deployed PEAQS in Sun Valley on August 18-19, 2020 in response to community complaints regarding the Devil's Gate reservoir restoration project. Per LAPW request, no citations were issued in order to minimize traffic delays in the region.

In 2021, as of the writing of this report, Mobile PEAQS had been deployed 11 times, and inspections were conducted at all deployments (see Table 5-2 below). CARB will continue Mobile PEAQs deployments throughout the remainder of 2021.

Table 5-2. Mobile PEAQS deployment dates and locations in 2021.

Date	Location Type	Location City	Vehicles screened	Citations Issued
March 16 - 17	CHP Scale	Otay Mesa	1251	11
March 23 - 24	Roadside	Port of LA/LB	1159	12
April 13 – 14	CHP Scale	Winterhaven	611	12
April 20	Roadside	Lake Elsinore	451	6
May 11 - 12	Roadside	Los Angeles	693	16
May 18 - 19	Roadside	Santa Maria	379	6
May 25	CHP Scale	Calexico	523	6
May 26	Roadside	Westmorland	256	6
June 15 - 16	Roadside	Los Angeles	520	12
July 13 – 14	Roadside	Port of LA/LB	1780	14
July 20 - 21	CHP Scale	Otay Mesa	1275	16

Over 2020 and 2021, CARB conducted 19 deployments of Mobile PEAQs. Figure 5-1 displays all 13 unique locations where Mobile PEAQS were deployed on a map of California (several locations were visited more than once). In addition, CARB screened 22,740 vehicles and issued 141 citations for non-compliance with our current regulations. These mobile deployments demonstrated that PEAQS is an effective tool for screening vehicles and for identifying non-compliance.

Figure 5-1. Locations of the 13 PEAQS deployment sites in 2020-21. Also shown are California highways and county borders.

Unattended PEAQs

For this pilot effort, CARB built and deployed two prototype PEAQS for long-term unattended deployment. The first unit, shown in Figure 5-2, was deployed in San Bernardino County in 2019. Except for two short periods where the unit underwent maintenance and repair, this site has been in continuous operation since 2019. The second unit was deployed in Riverside County in 2020. This system operated normally until December of 2020, at which point it was returned from the field for maintenance and upgrades. It will be replaced with an upgraded version, as discussed further in the Lessons Learned section of this chapter.

Figure 5-2. Unattended PEAQs system in operation.

The two unattended PEAQS systems have collected significant amounts of data, including traffic details, as summarized in Table 5-3. Vehicles Screened at PEAQS Semi-permanent Pilot Sites.Table 5-3. These prototype units have screened an average of 41,000 vehicles operating within California every month. Aggregate emissions data are not included in this report because data analysis mechanisms to separate TRU emissions from vehicle emissions are continuing to be refined (see Lessons Learned section below). Individual vehicle data (including emissions) are also not provided as these data are being used to support enforcement actions related to current regulations.

Table 5-3. Vehicles Screened at PEAQS Semi-permanent Pilot Sites.

Total Vehicles Screened	238,000
% Registered in CA	47%
% Out-of-State	53%
Average Monthly Vehicles, San Bernardino	8,000

Average Monthly Vehicles, Riverside	33,000

Concurrent REMD Testing

Due to the inherent differences in REMD measurement techniques, it was important to pilot vehicle testing techniques concurrently to assess how best to utilize these different vehicle measurement techniques in a complementary manner. In an effort to help understand nuances between the methods, for the first two weeks in November of 2020, CARB staff, in coordination with CDFA staff and participating contractors, piloted potential vehicle compliance tests techniques such as OBD and opacity testing in combination with multiple REMD platforms that have the potential to be used as emissions screening tools. This piloting effort occurred at a CDFA inspection site on the Nevada-California border at Mountain Pass and aimed to begin to answer questions related to the potential interplay between REMD systems and potential vehicle compliance tests such as:

- Can currently available REMD systems identify high emitting vehicles with potential emissions control-related issues?
- Could different REMD systems be used together as part of a future statewide network?
- How do vehicle emissions measurements from REMD systems relate to potential vehicle compliance tests that may be used as part of the future program such as OBD and opacity?

Site description

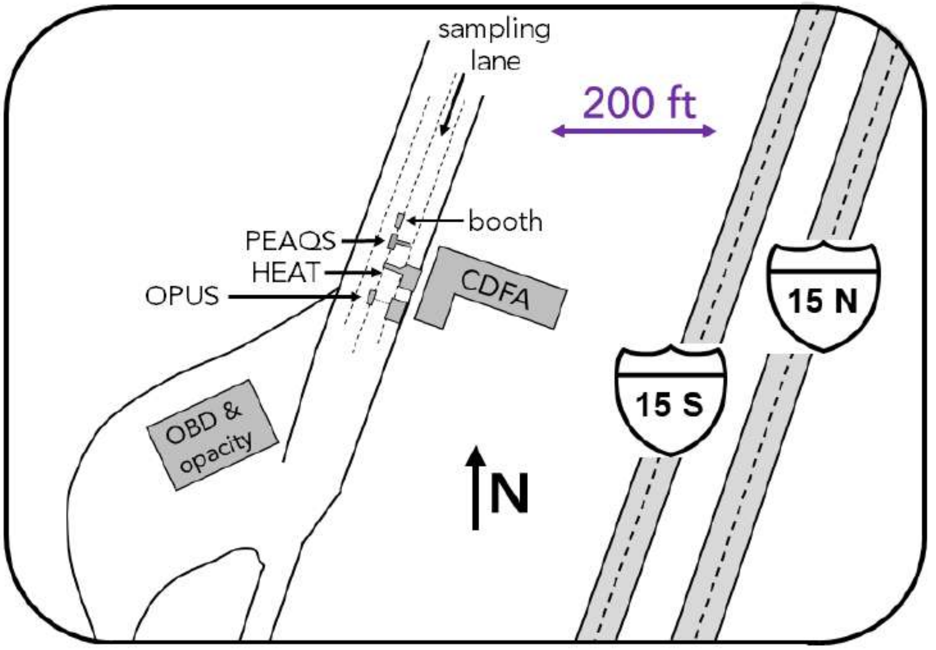


Figure 5-3. Diagram of the field site at Mt. Pass.

As shown in Figure 5-3, this piloting effort deployed three testing systems at the agricultural inspection station at the California-Nevada border along Interstate 15 (I-15). This station is located at 35.5161°N / 115.4319°W and is run by CDFA. This station has an Annual Average Daily Traffic (AADT) of 44,000 vehicles and 7,902 HDVs. The trucks entering California pass through the station immediately after climbing a 1.6 percent road grade averaged over the first 10 miles of I-15 south of the California-Nevada border, thus, it is expected that aftertreatment catalysts sampled during this campaign are above light-off temperatures. This station includes four HDVs lanes parallel to the I-15S highway. Emissions were measured from HDVs traveling along the second ("sampling") lane by three REMD systems – PEAQS, a system operated by Hager Environmental & Atmospheric Technology (HEAT), and then one operated by Opus Inspection, Inc. This sampling lane was the preferred lane for HDV traffic, and typically about half of the HDVs passing through the station did so in this lane.

A subset of the HDVs passing through the sampling lane was flagged for additional opacity testing and scans of their OBD system. These HDVs were selected at a CDFA booth situated immediately before passing through the REMD systems. Vehicle selections were made in an effort to obtain a representative sample of various OEMs and MYs. HDVs were observed by the three REMD systems, and immediately afterward drove over to the adjacent

OBD and opacity testing area. Participation in the opacity testing and OBD scans was voluntary, but a large majority (> 80 percent) of selected vehicles agreed to this testing.

In the sampling lane, emissions were first measured by CARB's PEAQS plume capture system. This system involved a sampling inlet comprised of perforated tubing crossing the lane above the height of the HDVs, as well as a lower inlet just above the ground along the side of the road. Immediately afterward, the HDVs were sampled by HEAT. This system involved a spectroscopic transmitter and receiver mounted about the roadway and a strip of retroreflective tape across the roadway below. Finally, emissions were measured by OPUS, which involved a spectroscopic transmitter and receiver mounted on either side of the road. OPUS used two horizontal spectroscopic beams – one a few inches off the road which targeted HDVs with downward-oriented exhaust pipes, and one approximately twelve feet off the ground which targeted upward-oriented pipes. All three systems reported fuel-based emissions factors - i.e., grams (g) NO_x or g PM per kilogram (kg) fuel.

HDVs flagged at the entry booth for secondary testing were subject to tailpipe exhaust opacity testing, using the SAE J1667 protocol. Results of this test are reported as a percentage. Opacity results above five percent for DPF-equipped vehicles are considered to have failed the test, although no citations were issued during this campaign. Applicable HDVs also had their OBD systems scanned, with scan devices manufactured by Silverscan and HEM Data.

PEAQS

CARB deployed a Mobile PEAQS unit at the Mt. Pass site (Figure 5-4). Fuel-based emission factors for NO, nitrous dioxide (NO_2), BC, and N_2O were quantified. Results for BC and NOx (NO + NO_2) are compared to other measurement systems below. Further details related to the PEAQS design and operation were discussed earlier in this chapter

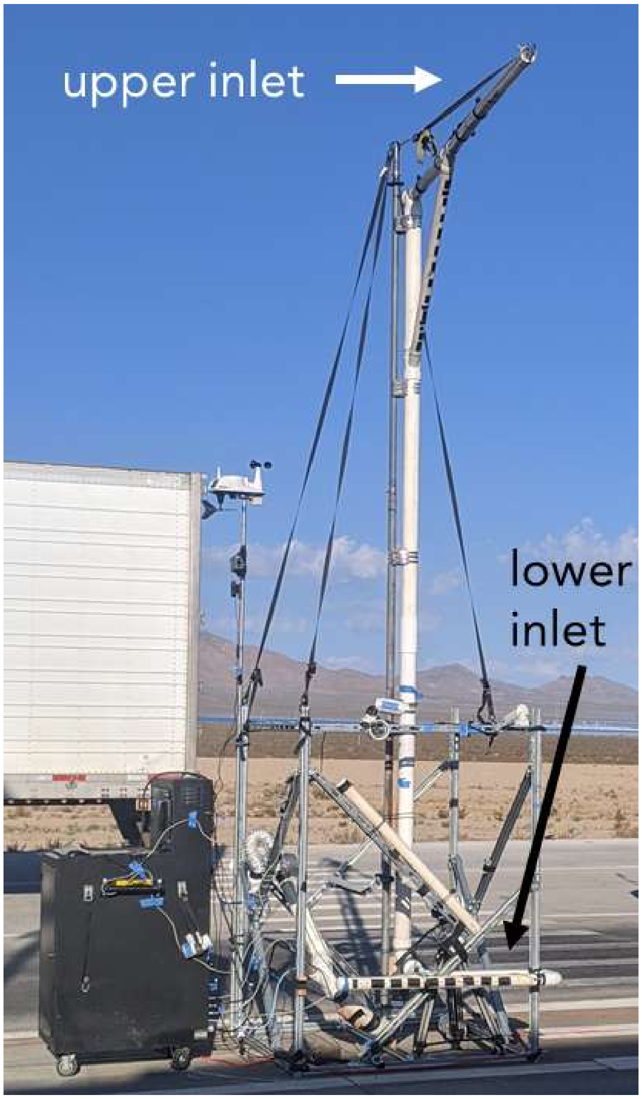


Figure 5-4. PEAQS unit in operation at the Mt. Pass testing site. Both the upper and lower sampling inlets are labelled.

HEAT

CARB contracted with HEAT to measure emissions from HDVs in the sampling lane. Using their EDAR system, HEAT measured fuel-based emissions of PM, NO, NO_2, carbon monoxide, and hydrocarbons (HC). EDAR involves an ultraviolet (UV)-visible light transmitter and receiver, mounted above the roadway and oriented downwards, along with a retroreflective strip installed across the roadway (Figure 5-5). It measures the differential absorption of various wavelengths of light as it travels downward from the transmitter, is reflected upward by the tape, and finally is received at the same location as it was emitted.

Figure 5-5. HEAT's EDAR system in operation at the Mt. Pass testing site. The combined transmitter/receiver is labelled.

OPUS

CARB contracted with Opus Inspection, Inc. to measure fuel-based emissions of PM, NO, NO_2, CO, and HC from HDVs in the sampling lane. The Opus system includes a UV-IR transmitter/receiver on one side of the road, and a reflector on the other (Figure 5-6). The absorption of light crossing the roadway in two beams was measured; the first beam was several inches off the ground and targeted HDVs with exhaust pipes below the vehicle, while the second was approximately 15 feet above the roadway and targeted HDVs with upward-oriented exhaust pipes.

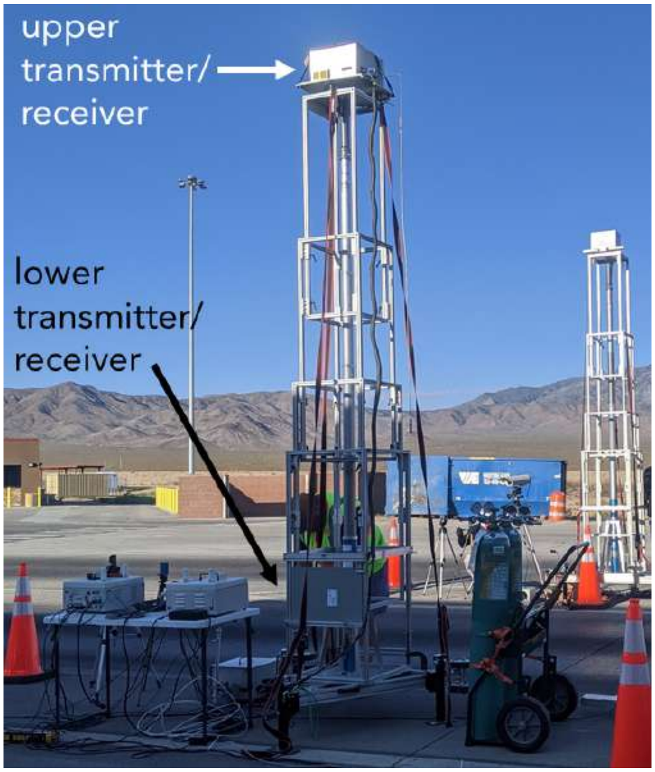


Figure 5-6. The Opus system in operation at the Mt. Pass testing site. Both the upper and lower combined transmitter/receivers are labelled. These use reflectors mounted on the tower on the other side of the road.

OBD scans

In addition to the fuel-based emissions factors observed by the spectroscopic and plume capture systems, a subset of the HDVs passing through these systems were also subject to scans of their OBD systems. Of the 169 HDVs sent to the inspection area, 127 (75 percent) agreed to the additional testing, 103 of which were OBD-equipped vehicles. Two devices were used to communicate with the OBD systems: a stand-alone logger manufactured by HEM Data, and PC software developed by Silverscan. Both devices were configured to record MIL status, active DTCs, diagnostic readiness, permanent DTCs, current drive cycle monitor status, and other engine information. The data collected in this pilot effort was similar to the data collected in the study described in Chapter 3 above.

Opacity Testing

Opacity readings were made on 118 HDVs following the SAE J1667 protocol. SAE J1667 applies to vehicle exhaust smoke measurements made using the Snap-Acceleration test procedure. The Snap-Acceleration Test procedure is completed on a non-moving vehicle and can be conducted along the roadside. It is designed to be used in conjunction with smoke meters using the light extinction principle of smoke measurement. A Red Mountain Smoke Check 1667 meter was used for testing, the same smoke opacity meters used by CARB Enforcement Field Representatives for field inspections.

Results

Vehicle Counts

Measurements were made from approximately 8 AM to 4 PM on 11 days: November 2 to 7 and 9 to 13, 2020. Emissions measurements were obtained from 12,837 HDVs passing through the RSD sampling lane. License plates from 9,499 unique vehicles were recorded, reflecting the multiple passes that many individual HDVs made over the eleven-day campaign. Many vehicles passed multiple times during the study; 61 HDVs passed through on at least six different days, and 506 passed through on at least three different days. Table 5-4 lists the number of observations made by each system.

Each REMD system was able to report emissions from a subset of the total HDVs that passed through the sampling lane. Many factors contribute to the various REMD systems not producing a 100 percent hit rate of valid emissions measurements for vehicles passing through the systems once data has completed quality assurance/quality control (QA/QC) checks, thus the measured hit rates are as expected. Reasons why emissions measurements may have been removed during the QA/QC process, and hence not reported, include interference from other vehicles, unfavorable wind conditions, measurements below the detection limit, and low signal-to-noise ratio, as well as others.

Table 5-4. Number of observations made by each system.

SYSTEM	VALID OBSERVATIONS
OVERALL	12,837
PEAQS	6,277
HEAT	8,987
OPUS	5,685

Measured by at least one REMD system

During this pilot effort, just over half of the vehicle population recorded was from jurisdictions outside of California (Table 5-5). Although the most common age range for both the in-state and out-of-state vehicles was the 2014-2017 MY range, the out-of-state HDVs were generally newer than in-state vehicles, as shown in Table 5-5, with nearly all out-of-state vehicles detected being 2014 MY or newer. Out of all out-of-state license plates detected, 49 percent were matched to the International Registration Plan. Out of observed California plates, 89 percent were matched with CA DMV registrations.

Table 5-5. Distribution of sampled trucks by age and license plate state.

CHASSIS MODEL YEAR	IN-STATE	OUT-OF-STATE
TOTAL	46.4%	53.6%
PRE-2007	0.8%	1.5%
2007-2009	3.1%	2.2%
2010-2013	11.2%	6.4%
2014-2017	21.4%	31.0%
2018-2021	9.9%	12.6%

Repeat measurements of individual HDVs

Over the course of the two-week, eleven-day campaign, many HDVs were observed multiple times by the REMD systems. Figure 5-7 shows that, for both NOx and PM emissions, hundreds of HDVs were measured at least three times by an individual system, and nearly fifty were measured at least five times. This relatively high repetition rate for the campaign allowed for an investigation of intra-system variability for individual vehicles passing through a system at different times. For this analysis, it is assumed that no changes to a vehicle's emissions control system occurred between measurements. For example, it is assumed that the durability of the emissions-related components is unchanged from the previous measurements and that no repairs or replacements of emissions-related parts occurred within the sampling window. Such assumptions are reasonable for emissions measurements within a short time period like the two-week sampling period under which this testing occurred.

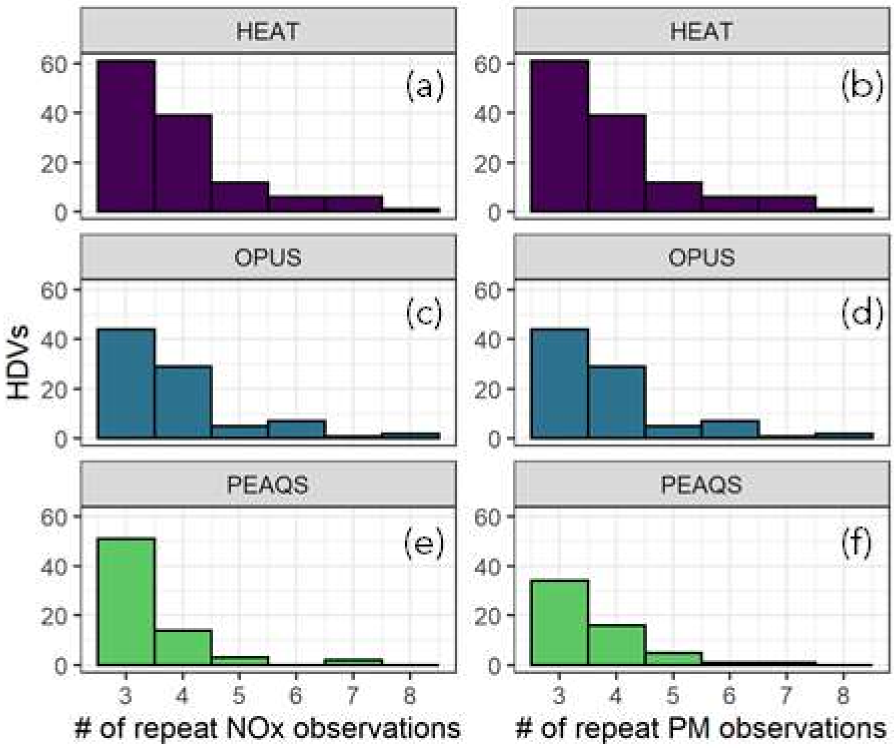


Figure 5-7. Number of repeat measurements of HEAT (a) NOx and (b) PM, Opus (c) NOx and (d) PM, and PEAQS (e) NOx and (f) PM. Note that only HDVs observed at least three times are shown.

Figure 5-8 depicts the average emissions for each HDV with a pollutant measured at least three times by the same REMD system, plotted from lowest emission measurement to highest. The error bars in Figure 5-8 indicate the standard error of the emissions measurements from repeat vehicles passing through the REMDs at different times during the campaign. For NOx emissions, average values for standard error were around 3 g NOx/kg fuel; the maximum standard error for a vehicle was 20 g NOx/kg. For PM emissions, average values for repeat measurement standard error were around 0.1 g PM/kg fuel; the maximum standard error for a vehicle was 3g PM/kg.

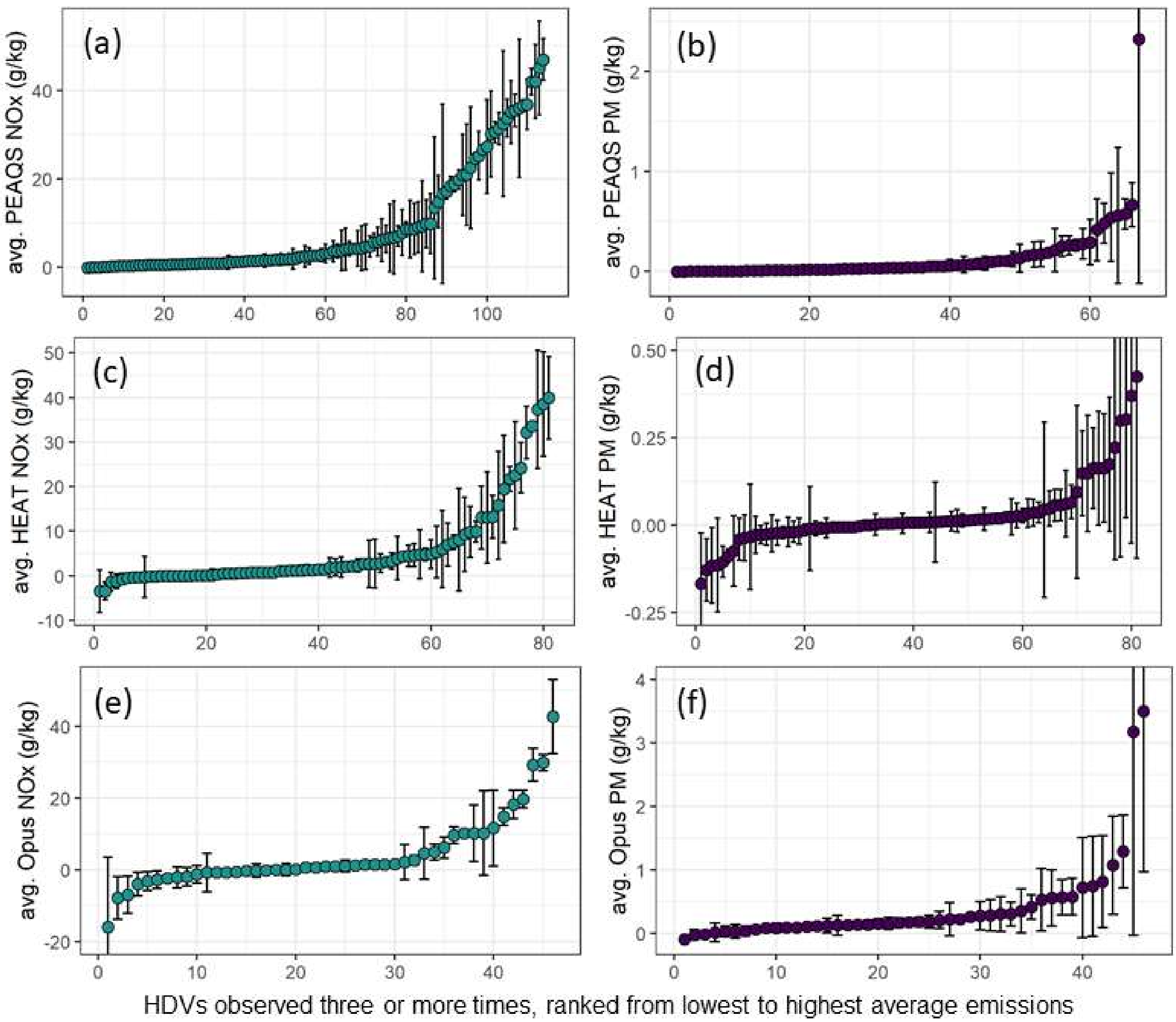


Figure 5-8. Average emissions of NOx (left) and PM (right), ranked from lowest to highest average emission measurement, for HDVs observed at least three times. Error bars depict standard error. (a) and (b) PEAQS; (c) and (d) HEAT, and (e) and (f) Opus.

Examination of the highest-emitting repeat measurement vehicles can give insight into the potential of individual REMD measurements to consistently identify potential high emitting vehicles if used to screen vehicles for future I/M action. A useful screening tool should flag the same high-emitting HDVs from day to day assuming everything else is constant. For all three systems, high emitting NOx vehicles could be reasonably and consistently identified during this campaign. The error bars between repeat measurements on these vehicles are small compared to the relative magnitude of the emission measurement and show that even with potential day-to-day variability, the vehicle's NOx emissions remained high. For example, the 18 highest emitters of NOx (16% of HDVs) as measured by PEAQS all were significantly (based on standard error) higher than 16 g / kg fuel. The highest six (5 percent) all were significantly higher than 31 g / kg (Figure 5-8a). Similarly, for HEAT, the eight highest NOx emitters (10 percent of HDVs measured at least three times) all were significantly higher than 10 g / kg (Figure 5-8c), and for OPUS, the top six (13 percent) were all significantly higher than 12 g / kg (Figure 5-8e). Based on these repeat measurements, all three REMD systems were able to reliably identify the highest NOx emitters (i.e., the top ~10%, or above ~10 g / kg). This indicates that the same HDVs would be flagged as high emitters from one day to the next. Overall, these results suggest that REMDs have the potential to be able to screen for vehicles with high NOx emissions.

Repeat measurements of PM emissions from individual vehicles were not nearly as consistent as for NOx emissions in this campaign. This is evident by the larger error bars (standard errors) relative to the magnitude of emissions measurements for PM, especially for vehicles that measured at the high end of the spectrum. The resulting day-to-day variation associated with the repeat PM emissions measurements during this campaign may be related to changing driving patterns of the vehicles in question at the time of measurement. Large spikes in PM emissions are typically correlated with acceleration events in a vehicle's driving pattern, thus any inconsistency in a vehicle's acceleration profile can impact the emissions measured from the vehicle. However, this repeatability may be less critical for PM-related high emitter screening relative to NOx screening. Considering HD vehicles operating in CA are predominantly operating with DPFs, any excess PM measurements, excluding regeneration events, are typically a sign that a vehicle's emissions control system has an issue. A properly functioning DPF reduces PM emissions by over 99 percent, thus effectively operating near background levels when functioning properly. So even if vehicle PM emissions may be inconsistent, identifying high PM emissions a couple times over the span of a short period to eliminate the anomaly that the vehicle may be passing through during a regeneration, may be enough to signal a potential maintenance issue. Testing will continue beyond this pilot effort to further identify the best methods to use REMDs as screening tools within the future HD I/M structure, however, upon investigations undertaken before and during this pilot effort, these systems have a strong potential to identify high emitting vehicles.

OBD scans

Summary

A total of 103 HDVs passing through the sampling lane were selected for OBD scans. The median engine MY for this sample set was 2017, and Figure 5-9 lists the engine OEMs observed, along with the number of HDVs for each. OBD data scans were obtained for 102 of these. One MY2013+ HDV from which OBD data was not obtained had a damaged OBD port. OBD data was therefore obtained from just over 99% (102 out of 103) of OBD-equipped HDVs selected for OBD testing.

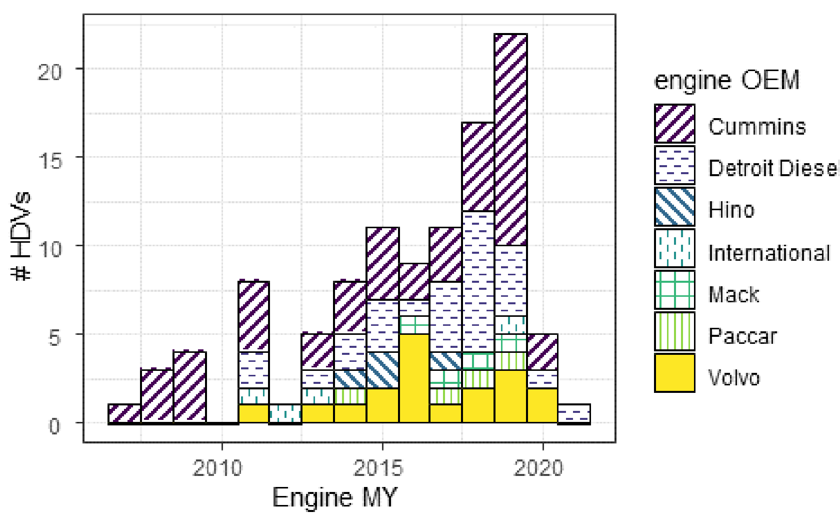


Figure 5-9. Engine MY distributions for HDVs subject to OBD scans. Color indicates engine OEM.

Malfunction Indicator Lamp status and Diagnostic Trouble Codes

Out of the 102 OBD-equipped HDVs that were scanned, 17 had their MIL illuminated resulting in a 17 percent MIL-on rate for the vehicles tested. Given the relatively small sample size of OBD tests in this two-week effort, this value is reasonably consistent with previous OBD test campaigns which have suggested a MIL-on rate around the 12 percent range. Nine of the seventeen engines had DTCs related to SCR operation (including the NOx sensors contained within the aftertreatment), making this the most common type of DTC observed. Five of these engines had DTCs related to engine operation, four had DTCs related to DPF performance, three had DTCs related to EGR, and one had a communications issue (note that some HDVs had DTCs in multiple categories).

Table 5-6 lists the DTCs associated with the MIL-on engines, and classifies them as either "active", "pending", or "permanent" as specified by the OBD scans. Between one and four DTCs were reported for each engine. As expected, every vehicle with an illuminated MIL had an active fault code associated with the vehicle's emissions control system. Of the total 29 active codes, 23 had a permanent fault code associated with the same emissions control issue. Permanent codes stay in the OBD system's memory even if fault codes are cleared and can only be removed once the vehicle has determined the fault detected is no longer present. These permanent codes can be a critical component in combatting fraudulent activity such as unhooking the battery or using a scan tool to clear fault codes prior to the submission of an OBD compliance test. The fact that a permanent code is associated with a high percentage (23 of 29, or 79 percent) of active codes collected in this effort suggests that incorporating permanent codes into compliance determination could help effectively combat some of the fraudulent activity that may occur prior to the submission of OBD tests.

Table 5-6. List of MIL-on engines and associated DTCs.

Engine MY	OEM #	DTC	active	pending	permanent
2017	1	Engine Crankcase Breather Oil Separator Speed	■		■
2018	1	Aftertreatment 1 Intake Gas Sensor 1 Heater Control	■		■
		Aftertreatment 1 SCR Intake NOx 1	■		■
2018	1	Engine Crankcase Breather Oil Separator Speed	■	■	■
2015	2	Aftertreatment 1 SCR Outlet Temperature	■	■	■
2014	2	Engine Coolant Level	■	■	■
2014	3	Aftertreatment 1 SCR Conversion Efficiency	■	■	■
		Engine Fuel Injection Pressure Error	■	■	■
		Engine Fuel Pump Pressurizing Assembly #1	■	■	■
2018	4	EGR "A" Flow Insufficient Detected	■		
2013	4	EGR Temperature Sensor "A" Circuit	■	■	■
		NOx Sensor Circuit	■	■	■
		NOx Sensor Circuit High	■	■	■
		NOx Sensor Heater Control Circuit	■	■	■
2015	4	NOx Sensor Circuit	■	■	■
		NOx Sensor Circuit High	■	■	■
2015	4	Cold Start SCR NOx Catalyst Inlet Temperature Too Low	■		■
		Exhaust Aftertreatment Fuel Injector "A" Performance	■		
2016	4	Particulate Filter Efficiency Below Threshold	■	■	■

Engine MY	OEM #	DTC	active	pending	permanent
		SCR NOx Catalyst Efficiency Below Threshold	■	■	■
		Ambient Air Temperature Sensor Circuit "A"		■	
		Reductant Tank Temperature Sensor "A"		■	
2016	4	PM Sensor Regeneration Incomplete	■	■	■
		PM Sensor Circuit Range/Performance	■	■	
2016	4	PM Sensor Regeneration Incomplete	■	■	■
		Turbocharger/Supercharger "A" Overboost Condition	■		
2015	4	NOx Sensor Performance - Sensing Element	■		
		NOx Sensor Heater Control Circuit Range/Performance	■		
		Catalyst System Efficiency Below Threshold		■	
2020	4	Lost Communication with Anti-Lock Brake System (ABS)	■		
2018	5	SCR NOx Catalyst Efficiency Below Threshold	■	■	■
2019	4	EGR "A" Flow Insufficient Detected	■		■

MIL-on duration

In addition to indicating MIL status, when the MIL is on, OBD systems report both (1) the distance the vehicle has traveled since the MIL was first activated and (2) the time the engine has been on since the MIL was first illuminated.

CARB has two sources of OBD data that include this information: the field campaign at Mt. Pass in November 2020 (seventeen HDVs, engine MYs 2013-2020), and the Truck and Bus Surveillance Program (eight HDVs, engine MYs 2015-2017). This latter program, which began in 2016, includes recruitment of in-use HDVs, followed by measurement of their emissions using both a chassis dynamometer and a PEMS. OBD scans are also collected. To obtain a larger sample size, these data sets were combined for this analysis.

Of the twenty-five HDVs with their MIL on, roughly half indicated that the MIL had been activated relatively recently. Specifically, for about half these HDVs, the MIL had been active for less than 100 engine-on hours (Figure 5-10), or less than 5,000 km (3,100 miles) traveled (Figure 5-11). The remaining half of these trucks had their MILs on for a wide range of durations. These MIL-on durations were spread evenly throughout the full range of possible reported values (up to 65,535 km, or 1,092 hours).

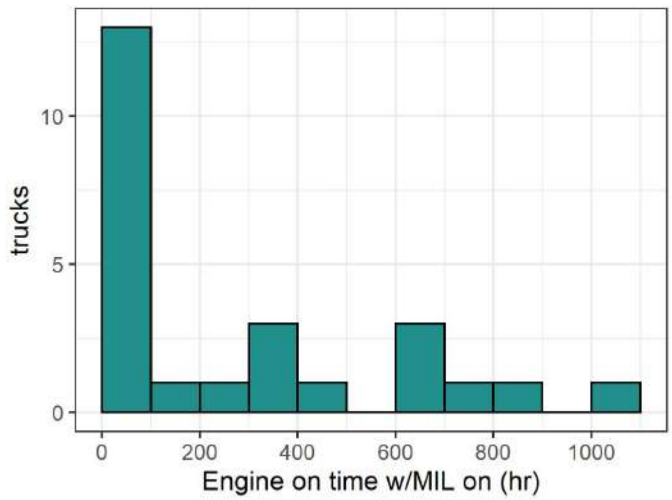


Figure 5-10. Distribution of engine-on time (hours) with MIL on, for HDVs with MIL on at the Mt. Pass site and in CARB's Truck & Bus Surveillance Program.

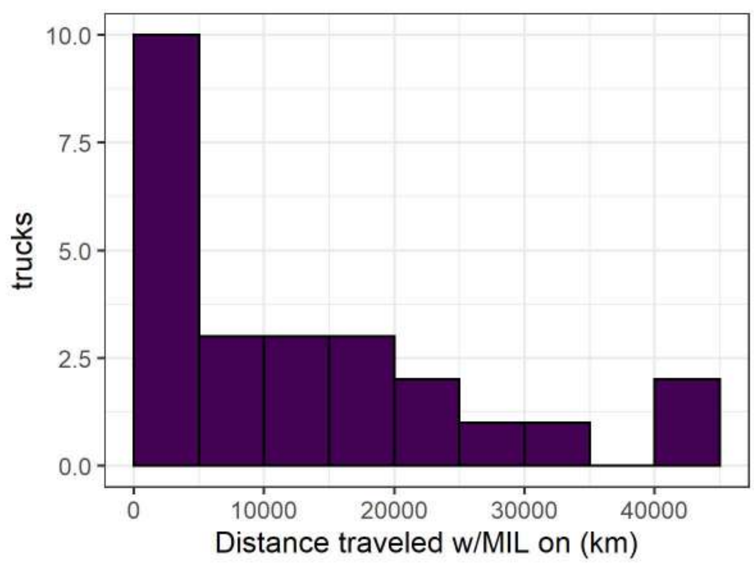


Figure 5-11. Distribution of distance travelled with MIL on, for HDVs with MIL on at the Mt. Pass site and in CARB Truck & Bus Surveillance Program.

Although this is a limited data set, the fact that about half of vehicles were operating with MIL-on for extensive amounts of time (i.e, more than 100 engine-on hours or 5,000 km (3,100 miles) traveled) highlights the need for an HD I/M program as a whole and highlights the need for frequent testing. The data suggests the potential that MILs are not being addressed quickly, and that a regulatory program such as a future HD I/M program can help create an incentive to prompt quicker repair action when a MIL is illuminated.

Opacity Measurement Results

CARB staff completed SAE J1667 opacity testing on 118 trucks. Eight of these (seven percent) measurements were above the five percent opacity limit for failure for DPF-equipped vehicles. For 96 of these (81 percent), the opacity measurement was 0 percent. All eight of the trucks that failed opacity testing had engines with engine MY older than 2013 (Figure 5-12).

No OBD equipped trucks failed the opacity test, yet 17 percent of them had illuminated MILs. Three percent of MIL-on vehicles had a DPF-related fault code, and yet still passed the smoke opacity test. This highlights an important potential feature related to these two vehicle compliance test types. OBD inspections are likely a stronger inspection method relative to the opacity test, and can more readily diagnose emissions control issues. This is highlighted by the fact that an OBD emissions test can diagnose potential malmaintenance issues prior to the emissions component completely failing. This is in contrast to the opacity test, where a failing result typically signifies that a DPF has failed and must be replaced. By the time the opacity threshold is exceeded, there is very little that can be done to salvage the DPF on the vehicle being tested. Although the sample size was small, it is still notable that no OBD equipped vehicles failed the opacity test. The observations that an OBD test is considered a stronger compliance inspection method than the opacity test and that no OBD-equipped vehicles failed the opacity test during this study potentially suggests that requiring an opacity test in addition to an OBD test simultaneously as part of a future HD I/M compliance test requirement for OBD vehicles may not be needed.

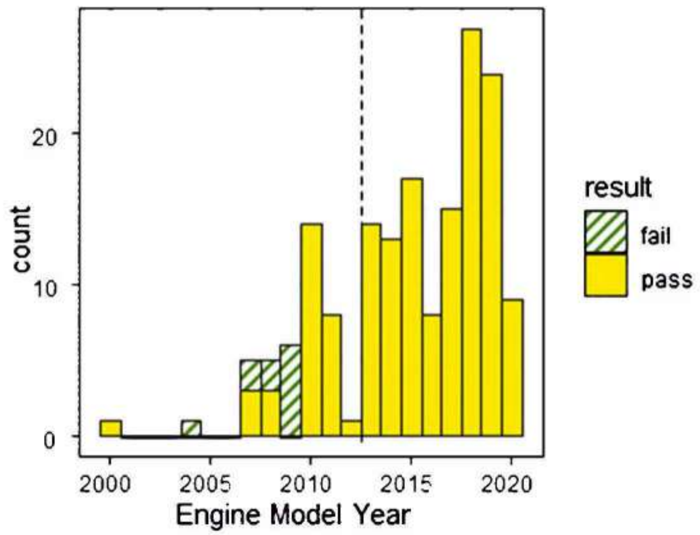


Figure 5-12. Engine MY distribution for trucks subject to opacity testing. Results of this testing are indicated by color (hatched green = fail, solid yellow = pass).

Comparison Among PEAQS/RSD and OBD Scans/Opacity Testing

The limited data set made it difficult to form strong conclusions about the relationship between REMD and potential vehicle compliance tests that may be used as part of the future HD I/M program. However, the data did show that the combination of REMD and follow-up OBD compliance tests could effectively capture a portion of non-compliant vehicles and ensure they are brought back into compliance. As noted, only 17 vehicles tested during this pilot effort had illuminated MILs. Of these tested vehicles, there was a mix between those that would have met the criteria to be considered a high emitter from one of the REMD and those that would not have been flagged by an REMD for further follow-up. Figure 5-13 offers an illustrative example of the relationship between REMD measurements and OBD MIL status as collected during this study. This figure depicted REMD measurements collected on the HEAT system with the horizontal lines representing the 95^{th} and 97^{th} percentiles of REMD emissions measurements, with markers above the lines representing vehicle emissions measurements in the top five and top three percent of those that were measured. Of the 17 MIL-on vehicles identified during this campaign, the majority of them would not have been identified as potential high emitting vehicles under a simple “top five percent” high emitter threshold within the REMDs themselves.

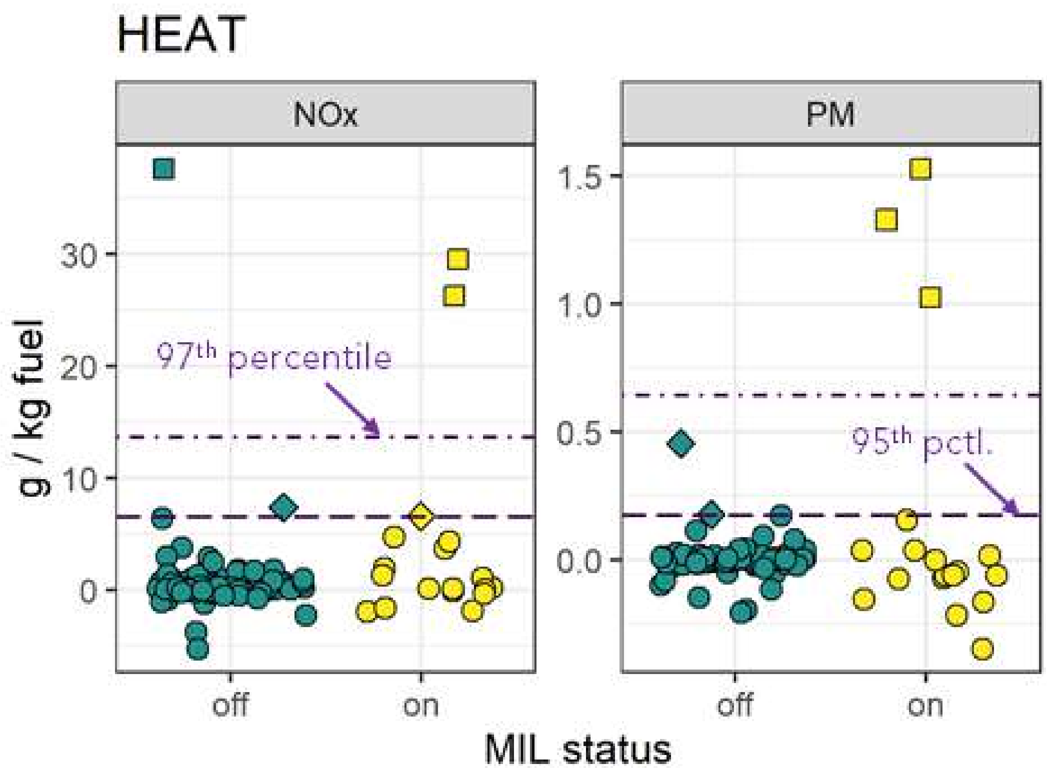


Figure 5-13. NOx (left) and PM (right) emissions measured by HEAT vs. MIL status. Horizontal lines indicate the 95th and 97th percentiles of all HEAT measurements. Points in the top three percent are squares, points in the top three to five percent are diamonds, and points in the lower 95 percent are circles.

Such a result is not unexpected, as a simple “top five percent” threshold is not robust enough to capture all the nuances of vehicle emissions. Collecting additional emissions data to improve REMD’s abilities to capture these nuances would result in REMDs capable of serving as strong screening tools, a deterrence to non-compliance, a method to screen between periodic testing, and a powerful tool to assess fraudulent activity. For example, vehicles submitting compliant periodic tests, but consistently operating at high emissions may suggest the vehicle should be looked at more carefully either for fraudulent activity or for malmaintenance between periodic testing. Thus, a program structure incorporating a periodic testing component in conjunction with REMD would result in greater emissions reductions overall and identify emissions-related repair issues earlier, rather than solely relying on REMD systems or periodic testing alone.

Lessons Learned

There were many lessons learned throughout the deployments of these REMDs. A discussion of these lessons learned is below. As a follow-up to this pilot, CARB staff are working to implement upgrades to improve the efficacy of REMDs like PEAQS.

Concurrence Testing

Three different REMDs were used to measure fuel-based PM and NOx emission factors from nearly 13,000 trucks crossing the CA-NV border over a two-week period in November 2020. The large number of vehicles measured on at least three separate days allowed intra-vehicle variability to be investigated. For repeated NOx measurements, vehicles with the highest average emissions (above ~10 g / kg fuel, or the top ~10%) were consistent, meaning that emissions were consistently high during individual passes through the REMDs. Overall, these results suggest that REMDs have the potential to readily identify high-emitting NOx HDVs for further I/M action.

In contrast, when PM emissions were measured from the same HDVs on multiple days, the individual measurements were much less consistent. Although not always repeatable and potentially due to variance in vehicle acceleration patterns, such repeatability may not be as critical for PM emissions measurements considering how effective DPFs are at minimizing PM emissions when functioning properly. PM measurements significantly above background levels potentially signal DPF related issues regardless of whether such measurements are always repeatable or not. Further testing will continue beyond these pilot efforts to further identify the best opportunities to use REMDs as screening tools within a future HD I/M structure, however, upon investigations undertaken before and during this pilot effort, these systems have a strong potential to identify high emitters.

Slightly over 100 vehicles were pulled over during the campaign for additional testing, including a scan of their OBD systems and a "snap-idle" opacity measurement. OBD data was obtained from 102 engine MY 2013 and later trucks. The MIL was illuminated in 17 percent of this subset, and approximately one-third of these had their MIL illuminated relatively recently (i.e., less than 100 hours of engine run time, or 5,000 km traveled). The majority had their MIL active for longer periods and distances. This suggests that an I/M program would have an impact on the speed at which emissions-related repairs are completed in the real world, leading to substantial emissions benefits by addressing these issues sooner. In terms of the individual components associated with MIL-on engines, the SCR catalyst was the most prevalent. A majority (95) of the vehicles tested had zero opacity, and eight (7 percent) failed the opacity test. All the trucks that failed the opacity test had engines older than MY 2013, and therefore were not OBD-equipped. The fact that OBD equipped trucks failed 17 percent of the time, but never failed an opacity test confirmed the need to move to OBD tests where feasible to diagnose emissions-related issues. Furthermore, this data suggests that adding an opacity test as an additional compliance test beyond an OBD scan for OBD equipped vehicles may not be a cost-effective approach to setting up an HD I/M program.

The relationship between REMD emissions and MIL status was not always consistent during this campaign using simple high emitter determinations such as "top five percent" of vehicle emissions measured in the REMDs. However, as mentioned previously, this result is not unexpected using a simplistic high emitter determination approach. The study highlighted the need to roll out REMD carefully and constantly monitor the outcomes so as to be sure a large number of vehicles are not being directed for further testing without identifiable or repairable emissions-related issues.

ALPR Implementation

Prior to unattended pilot deployments, PEAQS systems were periodically collecting static images from the ALPR camera and then post-processing these images with ALPR software. However, staff found that directly accessing the real-time stream improved the ALPR system's ability to identify license plate information. Implementing this new streaming ALPR improved the system's capture rate from ~80 percent to ~90 percent.

Matching Vehicle Emissions to their License Plates

The commercial ALPR software used in the PEAQS and other REMD systems generally performs very well, providing a 90 percent or higher capture rate (see above). However, there are occasional instances when a license plate is undetected by the software due to various reasons, such as blocked/obscured license plates and adverse lighting conditions. If this happens in combination with tailgating traffic, the chances that a vehicle's emission readings are misattributed to the following vehicle increases. To address this issue, REMDs may benefit from utilizing additional sensors like Laser Ranging Sensors as an additional vehicle detection mechanism.

Transport Refrigeration Unit Exhaust Mixing

HDV exhaust pipes come in two general configurations, either upward-pointing stacks with the exhaust emitted above and behind the cab of the HDV (updraft), or downward-facing exhaust pipes that emit below and behind the cab of the HDV (downdraft). In updrafts, TRU and HDV exhausts are located within a few feet of each other and their plumes can mix prior to being measured by an REMD. In the case of downdraft exhaust, TRU exhaust plume (if captured) and the HDV exhaust plume are either mixed in the transfer line, or they hit the sensor array within several seconds of each other. When this occurs, associating one with the HDV exhaust and the other with TRU is a challenging task. Addressing this challenge will likely require the integration of additional detection methods and/or computer vision techniques to confirm the presence of a TRU and subsequently determine the statistical likelihood of the emissions source (HDV exhaust or TRU).

Meteorological Impacts

Meteorological factors, particularly wind, impact the ability to collect air samples and relate emissions to specific vehicles. Collecting meteorological data and incorporating it into diagnostic analyses will allow REMD users to evaluate local, micrometeorological impacts to determine how weather affects the system's ability to capture plumes.

High Emitter Detection

Concurrent testing and continued deployments will help refine the high emitter detection algorithm for continued development of flagging techniques that could be utilized as part of any REMD component. For the purposes of this report's analysis, staff looked at the potential of utilizing a "top five percent" high emitter threshold for purposes of flagging potential high emitters. Using a simplistic "top five percent" screening approach would have resulted in some vehicles without a MIL-related issue being identified as a potential high emitter. And although the utilization of such a screening criteria would flag some MIL-on vehicles, it would result in others going unidentified. Although a small data set, such findings highlight that a more robust screening methodology would likely be more effective when incorporating REMD into a future HD I/M program as a potential screening tool.

Conclusion

The efforts in this chapter demonstrated that REMD, including PEAQs, are viable screening tools for the HD I/M program. In addition, the findings listed above will help CARB improve the various components of REMD networks. CARB will continue to develop the high emitter requirements to minimize flagging compliant vehicles (i.e., those without a detectable need for emission-related repairs), while identifying non-compliant vehicles for additional testing. These efforts will help reduce frustration from compliant regulated entities, build trust in the program, and improve emissions reductions all at the same time. CARB staff continues to enhance high emitter screening criteria and are assessing potential methods beyond a simple "top five percent" methodology. As more data is collected prior to the effective date of a future HD I/M program, REMD thresholds and decision support tools will continue to improve and help validate more robust screening criteria. Although more work is to be done prior to implementing the HD I/M program, the pilots have demonstrated the potential for both REMDs and OBD/opacity compliance tests to be used together in a comprehensive HD I/M program.

Chapter 6 San Joaquin Valley Pilot Repair Assistance Effort

Introduction

As discussed in previous chapters of this report, repairs to HDVs to get into compliance with the program may be costly, potentially averaging on the order of about $2,000. Due to this cost, such repairs may be difficult for some fleets, especially for smaller fleets with less financial flexibility. It is in this context that CARB performed studies as to whether a repair assistance program could fit without the constructs of a future HD I/M program. Also, the studies looked into how such a program could look.

CARB funded a one million dollar ($1 million) Grant Agreement with the San Joaquin Valley Air Pollution Control District (APCD) to administer a Heavy-Duty Vehicle Repair Program Pilot Project which offered financial assistance to small fleet truck owners and operators for emissions system related repairs. The overall goal of the Pilot Project was to determine whether a heavy-duty repair assistance program could be implemented alongside a future heavy-duty vehicle inspection and maintenance program. Additional information related to common emissions-related repairs and costs associated with the project were also gathered. As part of the tasks set forth within the Grant Agreement, the District developed program guidelines, applications, and participant surveys. The District entered into agreements with several HDV repair shops in the San Joaquin Valley to conduct repairs in the program. This chapter provides a summary of the activities that were performed by the San Joaquin Valley District. The full report provides more details and can be found in Supplemental Chapter C.

Project Description

The Grant Agreement designated $850,000 for repair costs, up to $100,000 for project implementation and $50,000 for administrative costs. During the course of the project, the District issued vouchers for 156 repairs. Each repair was classified into one of nine emissions categories (Table 6-1). There were 131 trucks repaired during the pilot, including 15 trucks that went through the program two times and five trucks returned three times. Trucks that went through the program more than once received vouchers for different eligible repairs that occurred during different visits to the repair shop. Ninety-five percent of the trucks were Class 8 vehicles (33,001+ GVWR), with a majority having an engine mode year between 2013 and 2017.

Table 6-1. List of eligible emissions categories.

EMISSIONS CATEGORY	DESCRIPTION
FUEL INJECTION SYSTEM	Injectors, wiring, fuel pumps, regulators, etc.
EXHAUST GAS RECIRCULATION	EGR valve, cooler, controls
TURBO CHARGER	Turbo Charger & Charge Air Cooler
COMPUTER SYSTEM	Computers, modules, wiring, connectors, lights
DIESEL PARTICULATE FILTER	Filter, regeneration system, monitoring system, lights
CATALYST (SCR[1])	Catalysts, DEF[3] dosing system, monitoring system, lights
CATALYST (TWC[2])	Catalysts, monitoring system, lights
SWITCHES / SENSORS	Sensors for oxygen, air flow, temperature, pressure, etc.
OTHER EMISSION CONTROLS	Intake / exhaust manifolds, valve adjustment, air filter, crankcase controls

[1] Selective Catalytic Reduction (typically used with diesel)

[2] Three-way catalyst (typically used with natural gas / gasoline)

[3] Diesel Exhaust Fluid

Heavy-duty repair shops participating in the pilot had to meet the following conditions:

- Based within the San Joaquin Valley APCD boundaries;
- Be certified by engine manufacturer(s) to perform repairs;
- Have the ability to provide itemized estimates and invoices with labor, parts costs, and applicable OBD codes;

- Provide an itemized invoice that documented the approach used to diagnose necessary repairs and document the time and cost of each performed repair; and
- Enter into an Agreement with the District to participate in the program.

As the project administrator, the District was responsible for determining vehicle, participant, and repair eligibility; selecting repair shops and implementing a process in which the repairs were diagnosed, conducted, and reimbursed; surveying and documenting the participants' satisfaction with and acceptance of the vehicle repairs; and evaluating the feasibility of implementing a large scale program. Additionally, the District was responsible for meeting with CARB's Project Liaison on a regular basis to provide status updates; description of any difficulties encountered, project milestones or deliverables; and notification of pending disbursement requests.

Results

Table 6-2 lists these emissions-related repairs by category and by repair shop. Of the eligible applications submitted, exactly half had the DPF system circled, 46% of all the applications contained an invoice with a type of sensor or switch in need of repair, while 28% contained Injection System repairs. The Catalyst (i.e., SCR) and the Turbocharger systems were addressed in 21% of all pilot project repairs. Repairs associated with the EGR system represented 18% of the total applications. The District concluded that some of the less common emissions systems repaired were in the Other Computer System category and Emission Control System category with their respective percentages of 13% and 10%. Lastly, the District found that there were no repairs associated with the Catalyst (OC, TWC) category. This category contained Catalyst components such as monitoring and warning lights which were not displayed on any service invoice sent in for the program.

Table 6-2. Number of approved repairs in each category, broken down by repair shop.

EMISSIONS CATEGORY	VALLEY TRUCK REPAIR	RDM DIESEL	MYERS DIESEL	% OF TOTAL
INJECTION SYSTEM	42	2	0	28%
EGR	25	2	1	18%
TURBO CHARGER	30	3	0	21%

EMISSIONS CATEGORY	VALLEY TRUCK REPAIR	RDM DIESEL	MYERS DIESEL	% OF TOTAL
COMPUTER SYSTEM	13	0	0	8%
DPF	70	6	2	50%
SCR	29	1	3	21%
SENSORS / SWITCHES	62	5	5	46%
OTHER	14	0	1	10%
TOTAL VEHICLES AT SHOP	141	7	8	

Analysis

Of note, the average costs of repairs during this repair assistance program were substantially higher than the average projected repairs costs for a future HD I/M program on the whole. Although these costs seem to contradict each other on the surface, such a result is not unsurprising. Considering there is no HD I/M program currently being implemented that effectively enforces vehicles to maintain their emissions controls, a large incentive (i.e., large cost savings) would be needed to bring owners into a study where they are showing government entities like CARB their vehicles have emissions-related issues. Furthermore, such a study also requires an additional administrative burden on the fleets themselves beyond what would be experienced if they did not participate in the study. Thus, it is expected that a study like this has a higher expectation to bring in vehicles in need of extensive repairs, whereas smaller, less expensive repairs would not be worth the trouble for owners to go through the extra hoops in making the repairs. Therefore, it would be expected that a repair assistance program, in general, would see higher overall repair costs relative to the average even if implemented in coordination with the HD I/M program. Such an expectation is consistent with repair cost trends seen in BAR’s LD smog check program as well relative to repairs that apply for state assistance.

Although the repair assistance program was successful in repairing vehicles overall, many hurdles exist to implement such a program. Noted in the results was that a $1 million investment resulted in only 156 vehicle repairs. Thus, a substantial monetary investment would be needed to support a statewide repair assistance program. Furthermore, the District did face several challenges when administering the program, and it is expected that similar challenges would exist implementing such a program statewide. As one example highlight in the District's report, several of the contracts with repair shops had to be amended during the course of the project, emphasizing the need for flexibility when implementing such a program. Although feasible on a small-scale effort like this study, implementing on a similar basis for a statewide effort may be increasingly administratively burdensome. Another issue highlighted in the District's report was that not all of the contracted shops submitted any repair requests. This suggests that future programs should recruit more repair shops than are desired in the final program, to account for those who (for whatever reason) do not end up actively participating.

Staff at the District found that one of the most challenging aspects of the program was to determine repair eligibility and recommend flexibility for this determination in a future program. Many eligibility determinations were not straightforward and required a District or CARB expert to reach out for further clarification and analysis. Such case-by-case determinations could become increasingly burdensome on a statewide basis and maintaining such a level of flexibility may not be practical. Emissions systems on heavy-duty trucks are complex and establishing standards for writing up repair requests and determining which repairs should qualify for a program such as this could be challenging. Exacerbating this challenge is the fact that, unlike light-duty repair requirements that are governed by the Automotive Repair Act, there are no established standards for writing up repair orders in the HD repair industry, which contributes to the challenge of evaluating repair requests for eligibility. If CARB were to establish a heavy-duty repair assistance program, the District recommends that clear guidelines for determining who qualifies for assistance and the dollar limits of assistance could be received, as well as setting minimum standards for heavy-duty repair facilities and for technician experience.

It is also worth noting that the HD I/M program focuses on commercial entities and businesses, a fundamental difference relative to the LD smog check program, which applies to private citizens. Also, with the Governors directive to transition the California fleet away from combustion as specified in EO-N-79-20 (Office of California Governor, 2020b), it could be difficult to justify using taxpayer funding to support a program to prolong the life of diesel combustion vehicles owned by commercial businesses who may have failed to maintain them properly. Consideration should be given relative to whether it is better in the State's interest to support the repair of combustion vehicles versus further supporting the transition to cleaner zero-emission technologies.

Conclusions

This project demonstrated a small-scale HDV Repair Program in the San Joaquin Valley. CARB provided the financial backing for the program, while the San Joaquin Valley Air Quality Management District administered the program. The District collected pre- and post-repair surveys and performed 156 repairs with the $1 million dollars allocated for this study. Although the study demonstrated that a repair assistance program could be feasible alongside the future HD I/M program, many hurdles would need to be overcome to implement such a program on a statewide scale.

Chapter 7 CARB In-House HD Repair Durability Study

Introduction

In order for the HD I/M program to be successful and attain its emission reduction goals, the following prerequisites must be achieved:

1. The program must require malfunctioning, high emitting vehicles currently on California's roads to be repaired;
2. The repairs must correct the problems causing the high emissions and reduce the vehicles' emissions.

CARB staff performed CARB In-House HD Repair and Repair Durability Study to pilot test how successfully seriously malfunctioning HDVs can be repaired and to observe how OBD fault codes can be used to help diagnose and repair HD vehicles. As part of the study, staff also sought to recapture the vehicles months to years after repair to observe how long effective the repairs were at keeping emissions low over time.

Because the study involved locating severely malfunctioning trucks and convincing their owners to allow their vehicles to be used in a State research project, the study also gave CARB staff an opportunity to interact with owners of malfunctioning trucks. In talking with these vehicle owners, CARB staff was able to better understand some issues that owners mentioned can potentially make it challenging for them to keep their trucks well maintained.

Further detail on the study design, test procedures and test cycles used for the study is provided in Supplemental Chapter D. Supplemental Chapter D also includes photos of the vehicles repaired.

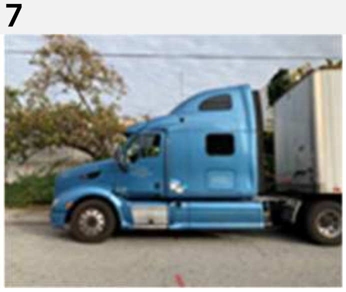
Vehicles Recruited, Defects Found, Repairs Conducted

Table 7-1 summarizes the characteristics of the vehicles recruited for the study and describes the HD OBD fault codes for each as well as the repairs performed.

Table 7-1. Summary of repairs made to HDVs.

NO.	TRUCK MY-MAKE-MODEL	ENGINE MY-MAKE-MODEL
1	**2012 Kenworth T800**	**2011 Cummins ISX-15**
	**Diagnostics / HD OBD codes:** • Engine Management Diagnostics (EMD+) No HD OBD, No MIL on • Dynamic Engine System Analysis (DESA) test results by Cummins dealer: – Diesel Oxidation Catalyst (DOC) Efficiency Fail – SCR Efficiency Fail	**Repairs:** DOC, SCR, NOx sensor
	1st Recapture	1 year after repair
	2nd Recapture	3 years after repair
2	**2013 Peterbilt 386 Series**	**2013 Cummins ISX-15**
	**Diagnostics / HD OBD codes:** • 1139, 1141, 1142, 1143, 1144, 1145: Injector Solenoid Driver Cylinder 1-6 Mechanical system not responding or out of adjustment • 3936: Aftertreatment 1 SCR Intermediate NH3 Sensor - Bad intelligent device or component • 3714: Engine Protection Torque Derate Condition Exists	**Repairs:** Cylinder Heads, 6 Fuel Injectors, Camshaft, DEF doser, doser gasket Coolant Leaking to fuel system repairs
	1st Recapture • 3714: Engine Protection Torque Derate Condition Exists	Diesel Dosing valve

NO.	TRUCK MY-MAKE-MODEL	ENGINE MY-MAKE-MODEL
	• 3568: Aftertreatment 1 Diesel Exhaust Fluid Dosing Valve 1 – Mechanical System Not Responding or Out of Adjustment	
3	**2016 Freightliner Cascadia 125**	**2015 DDC DD-15**
	**Diagnostics / HD OBD codes:** • 4364: SCR Conversion Efficiency 3364: DEF Tank Quality 1214: Aftertreatment 1 Outlet NOx • 3226: outlet NOx sensor	**Repairs:** ECU Reflush NOx sensors One-box (SCR+DOC) Radiator
4	**2014 Freightliner Cascadia**	**2013 DDC DD-15**
	**Diagnostics / HD OBD codes:** • Engine derated during PEMS testing • 5246: SCR Operator Inducement Severity • 3364: DEF Tank Quality 4364: SCR Conversion Efficiency	**Repairs:** 2 NOx sensors VPOD (Variable Pressure Output Device) DPF ACM (Aftertreatment Control Modules) Air brake valves
5	**2015 Freightliner Cascadia 125**	**2014 DDC DD-15**
	**Diagnostics / HD OBD codes:** Engine derated after major repairs • 3226: Aftertreatment Outlet NOx 1 • 5246: SCR Operator Inducement Severity • 4364: SCR Conversion Efficiency • 3364: DEF Tank Quality	**Repairs:** DPF NOx sensors One-box (SCR &DOC)
6	**2015 Kenworth T680**	**2013 Cummins ISX-15 425ST**

NO.	TRUCK MY-MAKE-MODEL	ENGINE MY-MAKE-MODEL
	**Diagnostics / HD OBD codes:** • 101: Engine Crankcase Pressure 1 • 81: Aftertreatment 1 DPF intake Pressure • 3720:Aftertreatment 1 DPF ash load percent data logger shows high ΔP >11 kPa • 81.16: Aftertreatment DPF system active regeneration occurring more frequently than intended as a result of a large amount of soot	**Repairs:** Crank Case Filter/sensor DPF
	1st Recapture • 3749: bad rear NOx sensor • 3226: Aftertreatment 1 Outlet NOx 1	NOx Sensor
	2nd Re-capture • 157: Engine Fuel 1 Injector Metering Rail 1 Pressure • 3464: Engine Throttle Actuator 1 Control Command	Fuel Injectors Crankcase pressure sensors In-frame kit Turbocharger DEF filter Bake DPF
	3rd Re-capture • 559: rail fuel pressure remains at least 100 Bar [1450 psi] less than commanded pressure	Fuel Lift Pump
7	**2014 Peterbilt 587**	**2013 Cummins ISX-15 525**
	**Diagnostics / HD OBD codes:** • Engine oil leak	**Repairs:** Predictive Maintenance Program DPF R/R twice within three years Turbocharger

Initial Improvement in Emissions

The study helps demonstrate that even vehicles with severely malfunctioning emission control systems could be repaired. The repairs succeeded in reducing both NOx and PM emissions, as summarized in Figure 7-1. On average, NOx and PM emissions were both reduced by 55 percent.

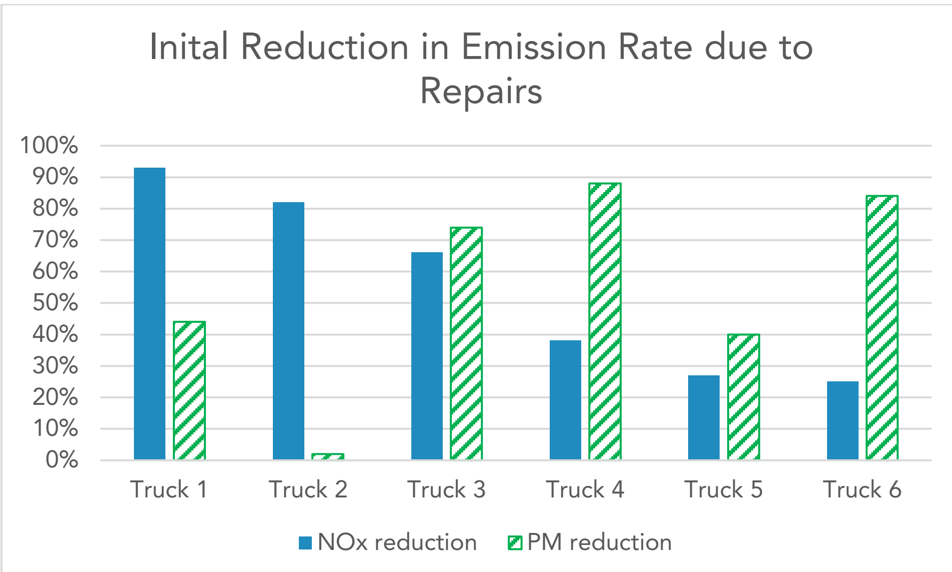


Figure 7-1. Initial reduction in NOx and PM emissions after repairs.

Repair Durability

It was difficult to recapture the trucks after repair, partially due to the covid pandemic. However, CARB staff successfully recaptured three trucks ranging from one month to three years after repair, Trucks 1, 2, and 6. As illustrated in Figure 7-2 and Figure 7-3 below, the initial repairs made were largely durable (i.e., emissions had not returned to their pre-repair state even after many months of operation on the road). Figure 7-2 below shows the NOx reductions after initial repair and then again after recapture. The NOx reductions after recapture were the same or slightly higher than upon initial repair, indicating the repairs achieved lasting NOx benefits. Figure 7-3 shows the PM reductions after initial repair and then again after recapture. Of the three trucks, only two, Truck 1 and 6 had PM-related repairs and so had initial PM reductions. For these two trucks, as for the NOx reductions, the PM reductions were lasting and apparent even after recapture.

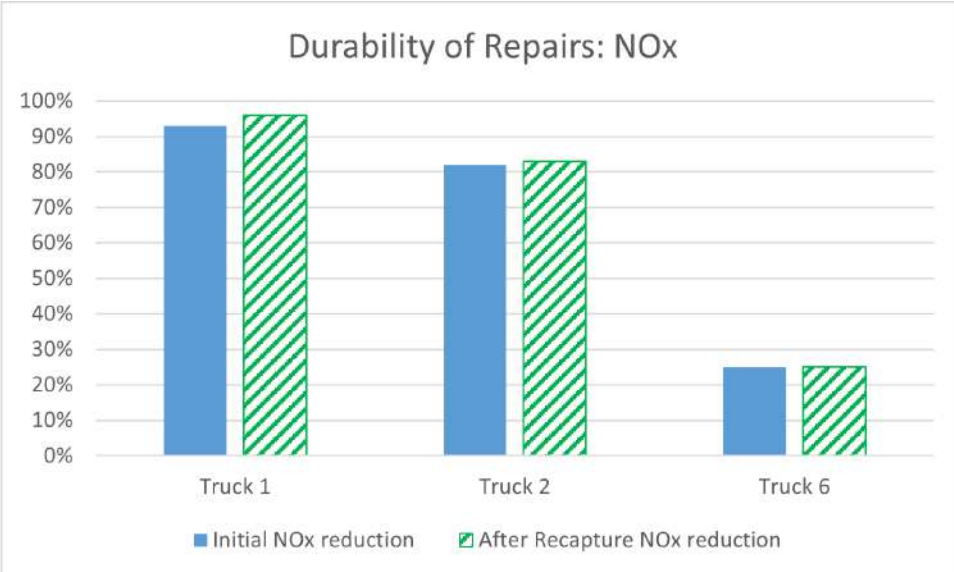


Figure 7-2. Comparison of NOx emissions reductions immediately after repair (blue) and after subsequent recapture (orange).

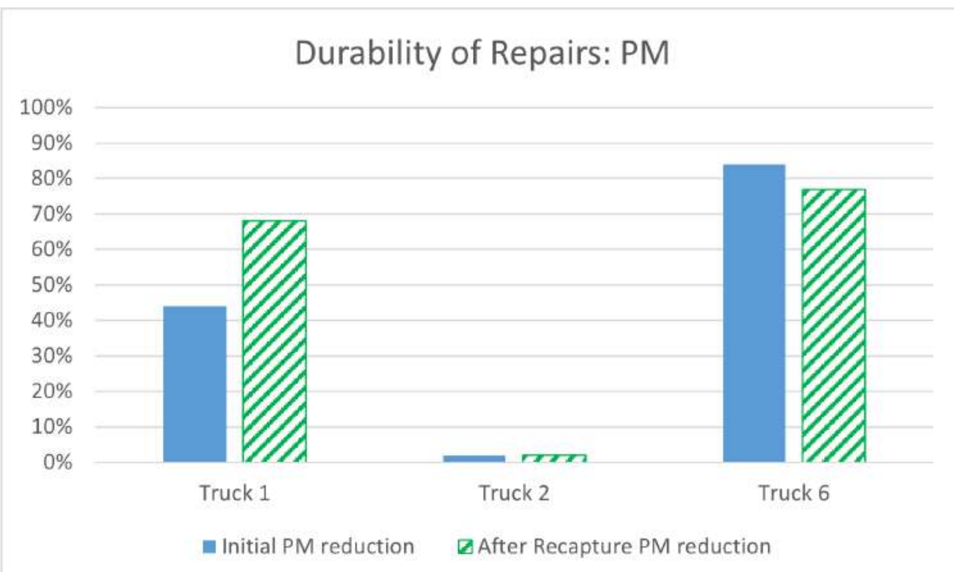


Figure 7-3. Comparison of PM emissions reductions immediately after repair (blue) and after subsequent recapture (orange).

Observations Regarding Emissions-Related Malfunctions

In the course of the study, CARB staff had the opportunity to interact with owners of malfunctioning trucks and talk with them regarding their experiences with emissions-related malfunctions. In talking with these vehicle owners, CARB staff was able to better understand issues that can make it challenging to keep trucks well maintained. CARB staff's observations from these conversations are summarized below:

1. Aftertreatment systems can be damaged by upstream engine problems that may be due to improper maintenance, tampering, and poor original engine manufacturer design. Unless these upstream engine problems are also diagnosed and repaired correctly, any repairs to the aftertreatment systems themselves will likely not be lasting. OEM-certified diagnostic technicians usually rely on OEM's diagnostic guidelines/repair trees to help with diagnosing issues with aftertreatment systems. It is also important for the technicians to understand the interaction between upstream engine issues and aftertreatment system issues, so they can quickly get to the root cause. For example, two testing trucks got a "DEF tank quality" fault code shortly after a DEF fluid refill. After replacing DEF fluid, NOx sensors, DEF filter, the fault code still existed. This occurred because the main issue was not addressed and was later found to be coolant leakage. Vaporized coolant had leaked from the radiator, and the moisture condensed on the NOx sensors by gravity which also explained why the newly replaced NOx sensors only lasted for a few weeks. Therefore, a thorough visual inspection to look over the entire aftertreatment systems, including the EGR all the way through to SCR was needed. Any visible leaks, excessive corrosion, or unusual wear may indicate a problem area.

2. Staff observed that when trucks were tested on the dynamometer with the MIL illuminated or certain mechanical problems, it could result in testing data being considered invalid. Emission measurement systems would automatically invalidate testing data when it detected an activated MIL or engine problem. Therefore, some trucks could not be tested on the dynamometer during this study. Staff found that, alternatively, data loggers and OBD scan tools can be used as a pre-screening tool to identify malmaintained trucks as part of this study and evaluate conversion efficiencies of aftertreatment devices. A real-time data streamer could continuously monitor a truck's emissions status such as DTCs, NOx conversion efficiency, and DPF's differential pressure changes.

3. Diagnosing through the repair tree can be difficult at times. Checking for previous trouble codes and looking at the previous repair history can provide additional direction beyond looking at the current vehicle OBD fault codes when assessing where to start a repair. Staff observed some situations where multiple fault codes made the initial repair diagnosis more difficult.

4. High repair cost and repair downtime were major concerns expressed to CARB staff by truck owners and operators during the course of this study. When the MIL is on or an engine is derated, truck drivers often use their own diagnostics scan tool and put the truck into a forced DPF regeneration to clear codes, and to remove derate associated problems without a visit to the OEM dealership. In addition, some truck owners and service providers prefer to repair the cheapest component first to see if it can solve the problem or to clear the fault codes and simply get back out on the road as quickly and cheaply as possible. However,

this process can end up costing the truck owner more time and money in the long run as the main repair issue is usually not addressed. Simply replacing the cheapest component and not looking holistically at the repair issue as a whole can result in the real maintenance issue not actually being addressed. This can result in the truck needing to come back to repair shop quickly with the same repair issue reoccurring, resulting in additional time in the repair shop spent troubleshooting the issue again, which leads to increased costs in the end.

Chapter 8 Conclusions

Senate Bill 210 directs CARB to conduct a pilot HD I/M program prior to taking an HD I/M regulatory proposal to the Board for potential adoption. In collaboration with stakeholders and other state agencies, CARB staff performed a pilot program to demonstrate technologies that could bring vehicles into the future HD I/M program. As part of this pilot testing effort, CARB and participating stakeholders pilot tested equipment that could be used to demonstrate compliance with the future HD I/M program, such as OBD collection and opacity measurement tools. Furthermore, the pilot program demonstrated potential vehicle monitoring equipment that could be used to enhance enforcement efforts and ensure more vehicle owners bring their vehicles into compliance with the future program. This included REMD technologies such as CARB's PEAQS system and instruments from leading remote sensing companies. ALPR cameras were also piloted to understand how to best optimize their use in the future HD I/M program.

The pilot effort to assess the feasibility of OBD data collection and compliance determination included collecting OBD data from real, in-use vehicles at several sites across California and other states. OBD data was collected through collaboration with two OBD device vendors. The effort verified that the OBD data CARB staff is considering to require as part of the HD I/M program could reliably be collected from HDVs and be used to determine emissions control compliance. OBD data collection was quick to perform and could be completed in under five minutes.

Both external and CARB-developed REMDs demonstrated effectiveness as stand-alone screening tools that could be used as part of the HD I/M program to identify potential high emitting vehicles. PEAQS, which was developed at CARB, has been deployed as both a mobile unit that can be moved to different locations based on future program needs and as an unattended, semi-permanent installation for long-term use. Unattended PEAQS deployments have screened over 238,000 vehicles at two CA sites for potential emissions control issues. During a two-week campaign in November 2020, PEAQS was deployed alongside two other commercial REMDs, and screened over 10,000 HDVs for potential emissions issues. Many HDVs were observed multiple times during this campaign, with NOx emissions being highly repeatable, including those from the highest emitters.

ALPR cameras were also tested as part of these pilot efforts, both through external contractor work and internal CARB work. Contractor field testing recorded vehicle capture rates of about 75 percent, however, further enhancements through CARB's internal PEAQS development efforts have improved vehicle capture rates to above 90 percent.

Beyond the specific SB210 pilot activities, several other efforts relevant to the development of the HD I/M program are also described in this report. First, contractors at

UC Riverside conducted a research study to assess potential design structures for a future HD I/M program and estimate the potential emissions benefits of a future program. The study recommended that a future HD I/M program incorporate an OBD based periodic testing approach complemented by an REMD component. Furthermore, the study estimated that an HD I/M program could reduce NOx emissions from the HD vehicle sector by about 50 to 75 percent.

Efforts were also undertaken by CARB and participating stakeholders to assess the potential repair costs that vehicle owners may incur to bring a vehicle back into compliance with a future HD I/M program and estimated average repair costs of about $2,000 per vehicle.

Another related project performed through a grant with the SJV air district assessed the potential of incorporating a repair assistance program as part of a future HD I/M program. Although feasible in the small-scale effort that was performed within the SJV region, this project identified several obstacles that could make a statewide repair assistance program difficult to implement.

Finally, CARB staff initiated an internal vehicle repair study to assess whether repairs could successfully be performed on vehicles with heavily damaged emissions control systems. The project successfully demonstrated that durable repairs could be performed and these vehicles could be brought back into a compliant status.

Overall, the pilot program and accompanying work have successfully demonstrated technologies that can be used as part of a future HD I/M program. Based on these results, CARB staff concludes an HD I/M program based on periodic OBD and opacity vehicle compliance tests is feasible. Furthermore, REMD systems can be used as an auxiliary mechanism to enhance compliance with a periodic testing program. Additional testing and research into all of these technologies will continue prior to the implementation of a future HD I/M program to further optimize their use in California’s HD I/M program, which will help ensure the future program brings as many vehicles into compliance as possible and is implemented smoothly and successfully.

Supplemental Chapter A

Final Report, Contact 15RD001

"Heavy-duty On-Road Vehicle Inspection and Maintenance Program"

Supplemental Chapter B

Final Report, Contract 18MSC001

"Heavy-Duty On-Board Diagnostic Data Collection Demonstration and Repair Data Collection Study"

Supplemental Chapter C

Final Report

Heavy-Duty Vehicle Repair Program Pilot Project

Supplemental Chapter D

Additional Information on CARB Repair Durability Study

Staff Report

California Air Resources Board Staff Report on the Warranty Cost Study for 2022 and Subsequent Model Year Heavy-Duty Diesel Engines

Prepared by Staff of the
Mobile Source Control Division
Mobile Source Regulatory Development Branch

December 2021

State of California
California Air Resources Board

This report represents CARB staff's findings related to each goal of the study. Although members of the work group reviewed and commented on the contents of this report, ultimately this report represents CARB staff's findings, and not necessarily a group consensus.

List of Acronyms and Abbreviations

Acronym/Abbreviation	Definition
ACT Research	Americas Commercial Transportation Research Co., LLC
ATA	American Trucking Associations
CARB or Board	California Air Resources Board
CBI	Confidential Business Information
CDA	Cylinder Deactivation
CE-CERT	The Bourns College of Engineering, Center for Environmental Research & Technology
CI	Confidence Intervals
CSUS	California State University, Sacramento
DEF	Diesel Exhaust Fluid
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
ECM	Engine Control Module
ECU	Engine Control Unit
EGR	Exhaust Gas Recirculation
EMA	Truck and Engine Manufacturers Association
EMFAC	CARB's EMission FACtor model
ERCs	Emission-Related Components
ERG	Eastern Research Group, Inc
EWIR	Emissions Warranty Information and Reporting
FET	Federal Excise Tax
FIR	Field Information Report
FTP	Federal Test Procedure
g/bhp-hr	Grams per Brake Horsepower-Hour
g/hr	Grams per Hour
GVWR	Gross Vehicle Weight Rating
HD I/M	Heavy-Duty Vehicle Inspection and Maintenance
HD OBD	Heavy-Duty On-Board Diagnostics
HDO	Heavy-Duty Otto-Cycle
HHDD	Heavy Heavy-Duty Diesel Engines >33,000 lbs. GVWR
HHDV	Heavy Heavy-Duty Vehicles >33,000 lbs. GVWR
hr	Hours
ISOR	Initial Statement of Reasons
ISR	Sacramento Institute for Social Research
lbs.	Pounds

Acronym/Abbreviation	Definition
L	Liter
LHDD	Light Heavy Duty Diesel
LLC	Low load cycle
MECA	Manufacturers of Emission Controls Association
MEMA	Motor & Equipment Manufacturers Association
MHDD	Medium Heavy Duty Diesel
MSCD	Mobile Source Control Division
mi	Miles
MIL	Malfunction Indicator Light
MY	Model Year
NOx	Oxides of Nitrogen
NREL	National Renewable Energy Laboratory
OBD	On-Board Diagnostics
OEM	Original Equipment Manufacturer
PM	Partuculate Matter
R&D	Research and Development
RMC	Ramped Modal Cycle
SCR	Selective Catalytic Reduction
SwRI	Southwest Research Insitute
TRUCRS	CARB's Truck and Bus Regulation Reporting
U.S. EPA	United States Environmental Protection Agency
US10 ERCs	ERCs meeting the current federal requirements
UL	Useful Life
yr	Years

Executive Summary

The Heavy-Duty Engine and Vehicle Omnibus Regulation and Associated Amendments (Omnibus Regulation), approved for adoption by the California Air Resources Board (CARB or the Board) on August 27, 2020, will dramatically reduce oxides of nitrogen (NOx) emissions by comprehensively overhauling exhaust emission standards, test procedures and other emissions-related requirements for 2024 and subsequent model year (MY) California-certified heavy-duty engines. The Omnibus Regulation includes updates to the warranty requirements because the current emission warranty periods are too short compared to the long life a typical heavy-duty vehicle is driven. For example, the largest heavy-duty trucks, heavy heavy-duty vehicles (HHDV), often stay on the road for nearly 1 million miles but are currently required to be covered under warranty for only 100,000 miles/5 years/3,000 hours, and 350,000 miles/5 years starting with MY 2022.

The new Omnibus warranty requirements, for example 600,000 miles/10 years/30,000 hours for HHDV starting with MY 2031, are critical because heavy-duty vehicles are enormous contributors to mobile source air pollution. They are likely to expose communities that are near roadways, close to ports, or adjacent to warehouse distribution centers to excessive pollution if they are not emission compliant and not durable for the actual useful lives.

Information from the original equipment manufacturers (OEMs) and a survey contracted by CARB and conducted by California State University, Sacramento, confirmed that most owners purchase extended warranties already, and the warranty costs will now be shifted fairly to the OEMs. Warranty is intended to help ensure defects in materials and workmanship get fixed but is not meant to protect OEMs from having to design durable components.

During the Omnibus Regulation rulemaking process, industry stakeholders raised concerns regarding the potential cost impact of warranty requirements. In response, the Board directed CARB staff to engage with affected stakeholders to conduct a warranty cost study. The Board's purpose for conducting this study was to better understand the differences between CARB staff's estimates of warranty costs and those estimates provided by industry stakeholders. The key findings of this study are summarized below:

- **CARB's method for determining the effect of the rulemaking on all owners is appropriate for considering the statewide impact**. Although the warranty cost estimates for MY 2022 made by CARB and those presented by the Truck and Engine Manufacturers Association (EMA) differ by a factor of nine, the warranty costs "per miles covered" reasonably agree. The average incremental miles covered under warranty in CARB's estimate is small because CARB's method accounts for the fact that most vehicle owners already purchase extended warranties voluntarily. They would not be affected by the rulemaking as much as those who have minimum regulatory warranties only. On the other hand, manufacturers' estimates only consider individual customers who do not already have extended warranty.

- **CARB staff believes it is simply part of the fundamental engineering cost to design durable components and does not believe that this cost should be attributed to warranty.** The warranty is intended to cover defects in materials and workmanship which cause the failure of a warranted part to be identical in all material respects to that part as described in the vehicle or engine manufacturer's application for certification. Therefore, warranty is not intended to cover failure of parts that are not designed properly. When the lower NOx standards take effect and longer useful life and warranty requirements are phased-in for MY 2027 and 2031, EMA's warranty cost methodology projects additional repair costs due to the lower NOx standards, higher unit prices for parts due to longer useful life, and the introduction of premature new technologies with elevated failure rates. CARB staff objected to these assumptions. Although there will be some new technologies introduced to meet MY 2027/2031 requirements, such as cylinder deactivation or light-off selective catalytic reduction, nearly all emission-related components expected for meeting the Omnibus standards will be the same as the technologies used today.

- **CARB staff concluded that even if the higher warranty costs for new technologies were included, it would not have changed the staff proposal.** CARB staff's additional sensitivity analysis suggested that if the warranty costs for new technology were included, it would increase the estimate of Omnibus Regulation costs by about 11 percent. The hypothetical increase was well within the bounds of the previous CARB Staff Report sensitivity analysis. This additional sensitivity analysis was conducted in response to EMA's comments during the working group, and evaluated the potential impact of new technologies on the warranty cost.

- **Results from CARB staff's fleet owner operator survey suggest that higher initial vehicle purchase prices are likely to be passed on to the subsequent vehicle owners, which potentially reduces the cost impact that the Omnibus Regulation warranty amendments may have on first owners.** A survey of fleet owner operators and dealers was conducted to better understand the value of remaining warranties to the purchasers of used vehicles. The survey results indicate that the remaining residual warranties do in fact add value to vehicles sold in the secondary market, averaging approximately $2,000 for a 2 years/200,000 miles period of residual warranties, and $4,000 for a 4 years/400,000 miles residual period.[1]

In conclusion, the Omnibus Regulation requirements continue to be cost-effective with benefits estimated to outweigh its costs by a factor of 10 (i.e., monetized benefits of $23.4 billion vs. costs of $2.39 billion). Although CARB staff does not concur with EMA's

[1] The values of individual residual warranties should not be confused with the average incremental cost of the regulation. For example, even if the required warranty period is increased by 200,000 miles, the average incremental cost can be much less than $2,000 since many owners already buy extended warranties voluntarily.

analysis methods, CARB staff agrees that the different viewpoints led to different baseline assumptions that ultimately affected the respective warranty costing methodologies. CARB's method included in the baseline optional longer warranties purchased in order to assess the impact of the rulemaking on the entire vehicle population. However, it is understandable that individual manufacturers would consider the first point they encounter their customers, rather than the average vehicle population. Since warranty is intended to cover defects, not inadequate design, CARB's estimate did not assume higher warranty costs (per miles covered) for MY 2027/2031 and instead accounted for the engineering cost as part of new standards, certification, and new technology. The work group members agreed that future warranty cost estimates should clearly list and clarify key assumptions on the definition of what should constitute warranty cost (e.g., distinction between useful life cost vs. warranty cost) and how the incremental coverage is calculated (e.g., how years/hours/miles limits are treated) because these are major sources of the apparent differences in estimates. Also, more data on residual warranty value would be useful in any future rulemaking that lengthens warranty requirements. Based on what has been learned from this study, overall, CARB staff believes that its methodology provides reasonable and defensible estimates of the average compliance cost that affected parties will face under the Omnibus Regulation.

I. Overview

The California Air Resources Board (CARB or the Board) approved for adoption the Heavy-Duty Engine and Vehicle Omnibus Regulation and Associated Amendments (Omnibus Regulation) at the public hearing on August 27, 2020. At that meeting, the Board further directed CARB staff to engage with affected stakeholders to conduct a warranty cost study. The Board's purpose for conducting this study was to better understand the differences between CARB staff's estimates of warranty cost and those estimates provided by industry stakeholders (reference Appendix A for the Board transcript).

Accordingly, CARB staff convened an industry stakeholder work group to analyze and study the various differences in the cost estimate methodologies used for estimating warranty costs. Industry stakeholders who participated in this study include the American Trucking Association (ATA), Cummins (the largest heavy-duty diesel engine manufacturer), the Manufacturers of Emission Controls Association (MECA), the Motor & Equipment Manufacturers Association (MEMA), and the Truck and Engine Manufacturers Association (EMA). The work group met a total of 16 times over a period of nine months. Additionally, CARB staff met individually with manufacturers (i.e., Cummins, Daimler, Paccar, and Volvo) to better understand industry's approach to warranty cost estimation practices, and any potential impacts arising from CARB's warranty requirement changes that will take effect with model year (MY) 2022.[2]

The work group established six specific goals for this study, as summarized below. In analyzing these goals, CARB staff worked collaboratively with the work group. This report represents CARB staff's findings related to each goal. Although members of the work group reviewed and commented on the contents of this report, ultimately this report represents CARB staff's findings and is not necessarily a group consensus.

Goal #1: Work collaboratively to better understand all of the assumptions made and all of the differences in the various warranty cost analysis methods

To address this goal, the work group improved the understanding of why there were large discrepancies between CARB and other's warranty cost estimates. The discrepancies stemmed from the philosophical differences in what should be the baseline and what warranty should cover. CARB's method considered all vehicle owners including those who would be affected less by the rulemaking because they were already buying longer than the

[2] In 2018, CARB approved for adoption longer emission warranty requirements for heavy-duty diesel engines that take effect with MY 2022. These amendments are known as the Step 1 warranty amendments. The Omnibus Regulation includes further lengthening of the emission warranty requirements beginning with MY 2027 that are known as the Step 2 warranty amendments.

minimum warranty. Also CARB staff assumed that the more rigorous heavy-duty engine durability demonstration program of the Omnibus Regulation would help ensure that parts are designed to be more durable. Therefore, warranty was assumed to only cover defects, as intended, rather than covering failures of parts that were not designed properly to meet lower emission standards and useful life requirements. CARB's method shifted the future repair cost to where it was intended, i.e., with Original Equipment Manufacturers (OEMs) designing emission durable components. On the other hand, EMA's analysis method focused on those who did not already have extended warranty (and who thus would be affected more by the rulemaking) and assumed higher repair costs as lower oxides of nitrogen (NOx) emission standards and useful life requirements would be phased in. When the analysis was limited to Step 1 warranty (no change in technology) and the effects of voluntary extended warranties were removed by estimating the warranty costs "per miles covered," CARB and OEM's MY 2022 warranty costs reasonably agreed as discussed below. Consequently, CARB staff concluded that its method was reasonable.

The work group discussed both Step 1 and Step 2 warranty amendments. This report focuses on evaluating per-engine costs for Heavy Heavy-Duty Diesel (HHDD) engines over 33,000 pounds (lbs.) gross vehicle weight rating (GVWR) unless otherwise noted.

Step 1 Warranty (MY 2022):

In 2018, CARB staff estimated the incremental warranty cost as the summation of the increase in emission-related repair costs and finance costs. Additionally, CARB staff estimated the rate at which parts would fail under Step 1 warranty using the then-most recent five years of the unscreened warranty claim data as reported to CARB by manufacturers in the Emission Warranty Information Reporting (EWIR) program. The baseline repair cost was estimated by multiplying the estimated failure rate and part price for each component. Other variables included projected and baseline miles covered, costs associated with linking the warranty to the on-board diagnostic system i.e., malfunction indicator light (MIL) costs, and financing costs. The procedure is summarized in equation I.1 as follows (see section IV.A.2 for more details):

$$[\Delta\, warranty\ cost] = [Baseline\ repair\ cost] \times \frac{[Projected\ miles\ covered] - [Baseline\ miles\ covered]}{[Baseline\ miles\ covered]} + [MIL\ cost] + [Finance\ cost].$$

(Equation I.1)

The incremental cost for Step 1 warranty was estimated to be $285 per HHDD engine. CARB staff described the methodology in detail in several work group meetings. The work group members suggested that staff compare CARB staff's estimated Step 1 warranty cost (i.e., $285) with the average price increase for MY 2022 products as compiled by EMA.

EMA gathered, aggregated, and averaged available cost data from OEMs for Step 1 warranty in June 2021 and provided it to staff. EMA reported that the incremental costs were approximately $3,750 for 15 liter (L) engines, $2,500 for 11-13 L engines, and $1,400 for medium heavy-duty (MHD) engines. CARB staff considered $2,500 for 11-13 L engines to be most relevant to this report; because the National Renewable Energy Laboratory (NREL), during their Omnibus Regulation cost study, received feedback from the industry that ~12-13 L engines with ~475 horsepower (hp) were more representative of HHDD engine platforms than 15 L engines (NREL, 2020).

Although the Step 1 incremental cost reported by EMA (e.g., $2,500 for 11-13 L engine) and CARB staff's estimate ($285 for HHDD) differs by a factor of nine, most of the apparent discrepancy can be explained by differing assumptions regarding the baseline and the endpoint of warranty coverages. CARB staff's analysis considers that most owners either voluntarily purchase longer warranties beyond current regulatory requirements or are gifted them during the sales negotiation process (ISR, 2017).

In its analysis, CARB staff included the miles covered under the optional longer warranties many truck owners already have into the warranty baseline because this approach more realistically reflects the actual baseline conditions before the Step 1 warranty takes effect. Also, CARB staff used CARB's EMFAC model to quantitatively determine the limiting factor of warranty requirements (miles, years, or hours) for each vehicle subcategory. But it was unclear if or how these significant miles/years/hours limiting factors were being considered in the costs estimated by OEMs. Specifically, CARB staff estimated that when the regulatory warranty requirements lengthen from 100,000 miles/5 years/3000 hours to 350,000 miles/5 years for MYs 2022-2026, the miles driven during the warranty periods would increase by only 32,100 miles as opposed to the apparent 250,000 increase of the warranty mileages (i.e., from 100,000 to 350,000 miles).

If the OEMs used the same failure rates and the repair costs as CARB but assumed a 250,000 increase in miles covered under warranty (i.e., from 100,000 to 350,000 miles), as opposed to CARB's estimate of 32,100 miles, the estimated incremental warranty costs would be $2,219 (i.e., $285 * 250,000 miles/ 32,100 miles), representing an increase of a factor of eight. During CARB staff's interviews with OEMs, one indicated that their volume-weighted average of the incremental warranty cost for MY 2022 HHDD was approximately $2,000 (excluding OEM markup or financing), indicating that on a per-mile basis, CARB and the OEM's MY 2022 warranty costs reasonably agreed.

Overall, CARB staff believes the staff's Step 1 warranty cost estimates prepared during the development of the Step 1 warranty rulemaking are still well-supported and appropriate even though at first glance they appear much lower than the prices OEMs will be charging their customers for longer warranties for MY 2022 vehicles. Staff's estimates appropriately account for the fact that many truck owners currently purchase warranty coverage much longer than the 100,000 mile minimum. In addition, staff's estimates also reasonably account for the fact that in many cases, warranty coverage ends up truncated not by the mileage limit, but by the accompanying year limit.

Step 2 warranty (MY 2027 & MY 2031):

CARB's Step 2 warranty cost estimate is lower than the others. This is because CARB's method considers all vehicle owners including those who would be affected less by the rulemaking (i.e., those who already have extended warranty and those who will reach the operation-hour limit first). CARB's method also assumes parts will be more durable to meet the durability demonstration program requirements of the Omnibus Regulation as discussed below.

CARB staff reviewed and compared its own Step 2 warranty cost analysis methods with those of NREL, America's Commercial Transportation (ACT) Research, and EMA. A summary of warranty costs and assumptions are presented in Table I.1. The details of each methodology are described further in section IV. Table I.1 highlights the differences in the assumed warranty coverage baseline, warranty coverage endpoints, NOx standards, and the assumption regarding future repair costs, which lead to the differences in the warranty cost estimates.

Table I.1. Summary of Estimated Step 2 Warranty Costs and Assumptions

	CARB Step 2 Warranty	NREL	ACT Research	EMA
Incremental warranty cost per HHDD engine[a]	$1,104	$23,061[b]	$7,227[c]	$13,091
Time periods	From MY2022 to MY2031	From MY2018 to MY2027[d]	From MY2019 to MY2031[d]	From MY2022 to MY2031
Warranty coverage baseline	500,000 mi/5 yr (40% of owners)[e]; 350,000 mi/5 yr (60% of owners)[e]	Current warranty offered by the OEMs (not provided to CARB)[f]	250,000 mi 2 yr	350,000 mi 5 yr
Warranty coverage endpoints	600,000 mi 10 yr 30,000 hr	800,000 mi 12 yr	800,000 mi 12 yr[g]	600,000 mi 10 yr
Assumed NOx standards, gram per brake horsepower-hour (g/bhp-hr) (federal test procedure (FTP)/ramped modal cycle (RMC))	0.020 @435,000 mi 0.040 @800,000 mi	0.02 @ 1 million mi	0.02 @ 1 million mi[g]	0.020 @435,000 mi 0.040 @800,000 mi

a: Caution must be taken when comparing the different costs because of the differences in the basic assumptions such as the baseline and warranty endpoints.
b: Average-cost diesel technology package 12-13 L with CA-only volume
c: HHDD at 7% discount rate with CA-only volume
d: The baselines of NREL and ACT Research are before Step 1 warranty becomes effective (MY 2022), which overemphasizes the discrepancy between CARB and NREL/ACT Research.
e: Assumes no preference for regulatory vs. voluntary warranty
f: Each OEM chose their own 2018 baseline. It is unknown whether the baseline is CARB-warranty or OEM-provided base warranty because details are confidential.
g: CARB staff asked ACT research for clarification but did not receive a response. These numbers are based on work group members' suggestions.

Completing Goal #1 helped the work group better understand the assumptions made in the various warranty cost estimation methods. The following major factors led to the differences between estimates by CARB staff and those by the other stakeholders:

1) CARB staff and EMA have different assumptions regarding the expected part failure rates under the new emissions standards and warranty requirements.

   CARB staff assumed that a properly engineered technology package designed to be durable throughout its useful life (e.g., 800,000 miles in MY 2031) would not have more unforeseen production errors (per mile) than current parts designed to last for 435,000 miles. This is because a warranty is not intended to address part failures that are not engineered properly. Implementation of the heavy-duty engine durability demonstration program in the Omnibus Regulation is expected to help ensure that parts will be designed to be more durable. Therefore, to estimate the rate at which parts would fail under the new, longer warranties, CARB staff used the actual failure rates from manufacturers obtained from CARB's 5-year warranty claim data (EWIR) for the most recent years for which complete data had been submitted, i.e., MY 2012 (Step 1) and MY 2013 (Step 2).

   Conversely, EMA's analysis projects more failures as new technologies are introduced and NOx standards lowered. For example, EMA's analysis assumed additional warranty costs for covering new technology (resulting in a 46 percent increase in the baseline warranty cost and the incremental warranty cost), higher failure rates due to the new 0.02 g/bhp-hr NOx standard (20 percent increase), and higher failure rates of new technology compared to mature technology (additional 20 percent increase applied to new technology). EMA's analysis did not consider that the new parts would need to be designed to last to the new useful life as CARB staff's did. It is possible that some manufacturers made similar assumptions when they responded to NREL and ACT Research's surveys, although the assumptions made by each manufacturer are confidential and were not made available to CARB staff.

2) Using California State University, Sacramento (CSUS) survey data, CARB staff more accurately accounted for current warranty buying practices by fleets and owner/operators than the NREL/ACT Research/EMA's analyses, and hence CARB staff's warranty baseline is higher than in the other analyses.

   CARB staff's warranty baseline is higher than NREL, ACT Research, and EMA's because CARB staff accounted for the fact that many heavy-duty vehicle buyers already optionally buy longer emission warranties. For example, 40 percent of vehicle owners who voluntarily purchased 5 years/500,000 miles warranties would be affected less by Step 2 warranty than those who had only Step 1 warranty (5 years/350,000 miles), which lowered CARB staff's estimated incremental costs.

3) CARB staff's warranty endpoint is shorter than that used in the NREL, ACT Research, and EMA analyses because CARB staff's analysis evaluated all of the factors that could have ended the warranty period (years, hours, or miles) based on the real-world vehicle usage parameters utilized by CARB's EMFAC inventory model. On the other hand, NREL, ACT Research, and EMA's methods did not consider the impact of hour limits in Step 2 warranty (see section IV.E.2. "Analysis of alternative scenarios" for more details). In addition, NREL and ACT's warranty endpoints were 200,000 miles longer than those used by CARB staff because their studies were based on an earlier CARB staff proposal (CARB, 2019) versus the endpoints that were ultimately proposed and approved for adoption by the Board (i.e., 1,000,000 miles vs 800,000 miles).

Goal #2: Gather available data for heavy-duty vehicles to quantify the residual warranty value to the second and subsequent owners.

In this section of the study, CARB staff conducted a survey, which suggests that the remaining warranty of a used vehicle will increase its resale value.

As the regulatory warranty periods are lengthened through Step 1 and 2, it is likely that more vehicles produced under these newer warranty requirements will be later re-sold in the secondary market as used vehicles with a portion of the lengthened warranty period coverage remaining (i.e., residual warranties). To better understand the secondary market value of such residual warranties, CARB staff conducted an online survey in April 2021 as part of Goal # 2, and collected 694 responses from fleets and owner/operators and from five dealers. The survey results indicate that the remaining residual warranties do in fact add value to vehicles sold in the secondary market, averaging approximately $2,000 for a 2 years/200,000 miles period of residual warranties, and $4,000 for a 4 years/400,000 miles residual period. The survey did not evaluate the impact of different year-to-mile ratios (e.g., 6 months/200,000 miles, etc.) because it would have added complexity to the survey process. Also, approximately half of the fleet owner/operators who responded to the survey indicated that they expected to hold on to their vehicles longer as warranty periods are lengthened. These results suggest that higher initial vehicle purchase prices which offset later repair costs will likely be distributed over longer time periods or passed on with their attendant benefits to the subsequent vehicle owners to some extent, which potentially will reduce the cost impact that the Omnibus Regulation warranty amendments may have on first owners as seen in the increased value recognized by subsequent vehicle owners.

Goal #3: Gather available data on usage patterns and duty cycles from the second and subsequent owners of vehicles used in a variety of applications to assess wear characteristics.

This section of the study clarifies the emission control component suppliers' views on what kinds of additional data will be useful for them to design more durable components.

During the Omnibus regulatory development process, suppliers noted the lack of data concerning the failure rates of parts beyond current required warranty periods. CARB staff has acknowledged that data reported to CARB was only within currently required and extended warranty time periods, which were shorter than those proposed in the Omnibus Regulation. This uncertainty resulted in an inability for suppliers to accurately estimate the costs associated with extending warranties to the levels in the Omnibus Regulation. Discussions between CARB staff and supplier representatives resulted in two concepts to be explored by the warranty work group. One possible concept suggested was to conduct a survey or test program to better understand the usage/duty cycles and wear characteristics of parts on vehicles operating at periods between current regulatory useful life/warranty requirements and Omnibus requirements. To this end, CARB staff gathered available data from recent studies as discussed below. However, it was not feasible for CARB staff to collect new data within the timeframe of this warranty cost study nor to commit to conduct a long-term study. The second possible concept suggested was for CARB to facilitate information sharing between suppliers and their OEM customers, which is represented by Goal 4 and Goal 5 below. This suggestion was later canceled based on the work group's discussions of Goals #4/5.

MECA and MEMA represent the suppliers of engine and exhaust emission control components used by OEMs, and specifically requested that Goal #3 be included in the warranty study. CARB staff discussed with MECA and MEMA representatives what relevant studies would help these suppliers better understand usage and wear analysis of parts on vehicles in various applications as warranty is lengthened. Having a better understanding would help the suppliers determine where more development is needed to meet Omnibus requirements as well as more accurately estimate the costs to suppliers of extended warranty requirements. Based on the discussions, CARB staff provided the following resources to MECA and MEMA members:

- "Collection of Activity Data from On-Road Heavy-Duty Diesel Vehicles" (CE-CERT, 2017)
- CARB EMFAC Fleet Database: https://arb.ca.gov/emfac/fleet-db
- "Updates to Heavy-Duty Emission Deterioration in EMFAC" (ERG, 2020)
- "Heavy-Duty Vehicle Accrual Rates" (ERG, 2019)

Subsequently, although MECA and MEMA members found the information helpful, they suggested that CARB staff conduct a more detailed study to investigate the wear characteristics of used (not failed) components and provide more details about the failures of components, such as the mileage and season of the year in which the failure occurred, oil/fuel usage, and duty cycles. There is a particular lack of data in the usage and maintenance patterns of second and third vehicle owners. While this suggestion has merit, such a study is beyond the scope of this warranty cost study.

Goal #4: Make a plan for gathering and sharing data between OEMs and suppliers as new technologies to meet MY 2024 and MY 2027 standards are rolled out.

As part of Goal #4, CARB staff attempted to understand the business relationships more comprehensively between OEMs and emission control component suppliers so as to possibly assist them in meeting the new standards. However, in CARB staff's discussions with MECA and MEMA representatives, it became clear that the structure of these OEM-supplier business relationships varied widely and that sensitivities existed with information sharing. Therefore, the group decided that there was not a clear path for CARB to intervene between OEMs and suppliers to facilitate information sharing beyond what exists today. As a result and as recommended by MECA and MEMA representatives, CARB staff subsequently decided against conducting a survey related to this goal as was originally anticipated, and no further action was taken. As part of this study, CARB staff met individually with OEMs and confirmed that some OEMs are in discussion with suppliers regarding MY 2022 warranty requirements. CARB will continue to monitor the process as the industry prepares to meet MY 2024 and MY 2027 requirements.

Goal #5: Facilitate discussions between OEMs and emission control component suppliers beyond the current 100,000-mile warranty period.

Similar to Goal #4, CARB staff initially planned to conduct a survey of OEMs and component suppliers about a broad range of issues ranging from learning about the information exchange that occurs during the development process in designing component specifications to determine how warranty claim information is shared and who pays for the cost of replaced components. However, CARB staff decided against conducting a survey at the recommendation of MECA and MEMA representatives, which was based on the same reason stated for Goal #4 above. As an alternative, CARB staff analyzed the top two to three failure modes from warranty data submitted by engine manufacturers to CARB from Field Information Reports (FIR) to provide additional information for suppliers. The claims were reported for a 5 year period, but they included claims covered by the 5 year/100,000 miles/3,000 hours warranty, base engine warranty, and paid extended warranty. For example, major failure modes of sensors are shown in Table I.2 below.

Table I.2. Common failure modes of sensors determined by examining FIRs for the 2013-2019 MYs

Components	Failure modes
NOx Sensor	1. Moisture contacting sensor element 2. Cracking due to thermal shock 3. Software Issue
PM Sensor	1. Clogged sensor tip 2. Software Issue
Ammonia Sensor	1. Sensor circuit error 2. Rusted/Corroded
Urea Quality Sensor	1. Liquid Ingress 2. Communication Error

The failure mode analysis included major components such as injectors, selective catalytic reduction (SCR) components, diesel particulate filters (DPF), exhaust gas recirculation (EGR) components, and turbochargers.

Goal #6: Review the study's results and determine the suggested next steps from the study.

Over the course of the work group study, CARB staff collected information from stakeholders related to cost estimates for warranty costs and convened 16 separate work group meetings to discuss various aspects of warranty costs. This included inviting both NREL and ACT Research to present or attend discussions on their own warranty cost analyses. Brief summaries of the activities conducted to accomplish each goal, and the suggested next steps of each goal are provided in Table I.3.

Table I.3. Summary of suggested next steps

#	Goals	Suggested next steps
1	Work collaboratively to better understand all the assumptions made and all of the differences in the various warranty cost analysis methods.	Future warranty cost estimates should clarify key assumptions on the definition of warranty cost (e.g., distinction between useful-life cost vs. warranty cost) and how incremental coverage is calculated (e.g., how years/hours/miles limits are treated) since these are major sources of the apparent discrepancies.
2	Gather available data on heavy-duty vehicles to quantify the residual warranty value to the second and subsequent owners.	As warranty periods become longer and more used vehicles are sold with residual warranties in the future, it may be helpful to collect more sales data on the value of residual warranties of actual vehicles.
3	Gather available data on usage patterns and duty cycles from the second and subsequent owners of vehicles used in a variety of applications to assess wear characteristics.	MECA and MEMA representatives suggested CARB should consider future long-term studies that collect information on: • Mileages of the vehicles studied • Location of the SCR temperatures (inlet or outlet) • Season of study, summer versus winter • Oil and fuel usage
4	Make a plan for gathering and sharing data between OEMs and suppliers as new technologies to meet MY2024 and MY2027 standards are rolled out.	None. CARB staff was advised by MECA and MEMA representatives to not conduct a survey to understand OEM-supplier relationships since their business relationships varied widely, and CARB should not interfere with their relationships.
5	Facilitate discussions between OEMs and suppliers beyond the current 100,000-mile warranty period.	Same as #4

Although CARB staff and the work group members were unable to agree on all the elements of warranty cost estimation methods, it became clear that the cost information used (e.g., EMA's aftermarket warranty price vs. CARB's repair cost) and the types of costs that should be included (e.g., distinction between research and development (R&D) cost vs. warranty cost) were significantly different. The work group members agreed that future warranty cost estimates should clearly list and clarify key assumptions on the definition of what should constitute warranty cost (e.g., distinction between useful life cost vs. warranty cost) and how the baseline incremental coverage is calculated (e.g., how years/hours/miles limits are treated) because these are major sources of the apparent differences in estimates. Also, more data on residual warranty value would be useful in any future rulemaking that lengthens warranty requirements. As useful life and warranty are increased in 2027 and 2031, it also would be beneficial for emission control parts manufacturers to have more information on the usage patterns of vehicles as they are transferred to second or even third owners within the longer useful life.

CARB staff reviewed and analyzed multiple industry methodologies for determining warranty costs. As stated previously, the assumptions play a significant role. Fundamental differences in the interpretations of warranty coverages and costs as well as other detailed factors identified in this study explain the large discrepancy in warranty costs as estimated by CARB, ACT, EMA, and NREL.

A "waterfall" chart in Figure I.1 shows the causes of the different warranty cost estimates and the cumulative effects of major assumptions of EMA's analysis of aftermarket warranty pricing information (see section IV.D.2 and IV.E.2 for more details). The effect of each assumption is shown as a percent change compared to the previous scenario (one immediately to the left on the chart) therefore the summation does not equal 100 percent. For example, scenario #7 removes EMA's assumption of a 20 percent higher failure rate for new technologies to meet the MY 2027/2031 standards and other requirements. The overall impact of the 20 percent new technology factor is 8 percent because the new technology factor does not apply to the existing technology. The percent changes depend on the order of the scenarios and therefore should be considered as a rough guide for evaluating the impact of each assumption. The assumptions for new technology and the lower NOx standard (i.e., whether or not elevated failure rates are necessary) as well as incremental warranty coverage (i.e., warranty baseline and endpoint considering years/miles/hours) explain the majority of the differences.

EMA's assumption regarding the warranty cost of new technology resulted in the largest relative cost impact (i.e., 58 percent). CARB staff did not separately account for additional warranty costs from new technology costs for several reasons. First, although there would be some new technologies introduced to meet MY 2027/2031 requirements, such as cylinder deactivation or light-off SCR, nearly all emission-related components expected for meeting the Omnibus standards would be the same as the technologies used today. Second, CARB staff believes it is simply part of the fundamental engineering cost to design durable components and does not believe that this cost should be attributed to warranty.

However, in response to EMA's comments during the working group, CARB staff performed an additional sensitivity analysis evaluating the assumption of the warranty costs for new technology and estimated that if the warranty costs for new technology were included, it would increase the estimate of Omnibus Regulation costs by about 11 percent. The hypothetical increase was well within the bounds of the previous CARB Staff Report sensitivity analysis that incorporated the incremental warranty costs from the NREL report (CARB, 2020; see chapter IX.F). Therefore, CARB staff concluded that even if the higher warranty costs for new technologies were included, it would not have changed the staff proposal. More details of the additional analysis are shown in Appendix I.

Overall, CARB staff believes the methodology used to support the Omnibus Regulation warranty-related cost estimates is reasonable and defensible. Based on what was learned further in this study, staff continues to believe that the benefits of the Omnibus Regulation clearly outweigh its costs by a factor of 10 (i.e., monetized benefits of $23.4 billion vs. costs of $2.39 billion).

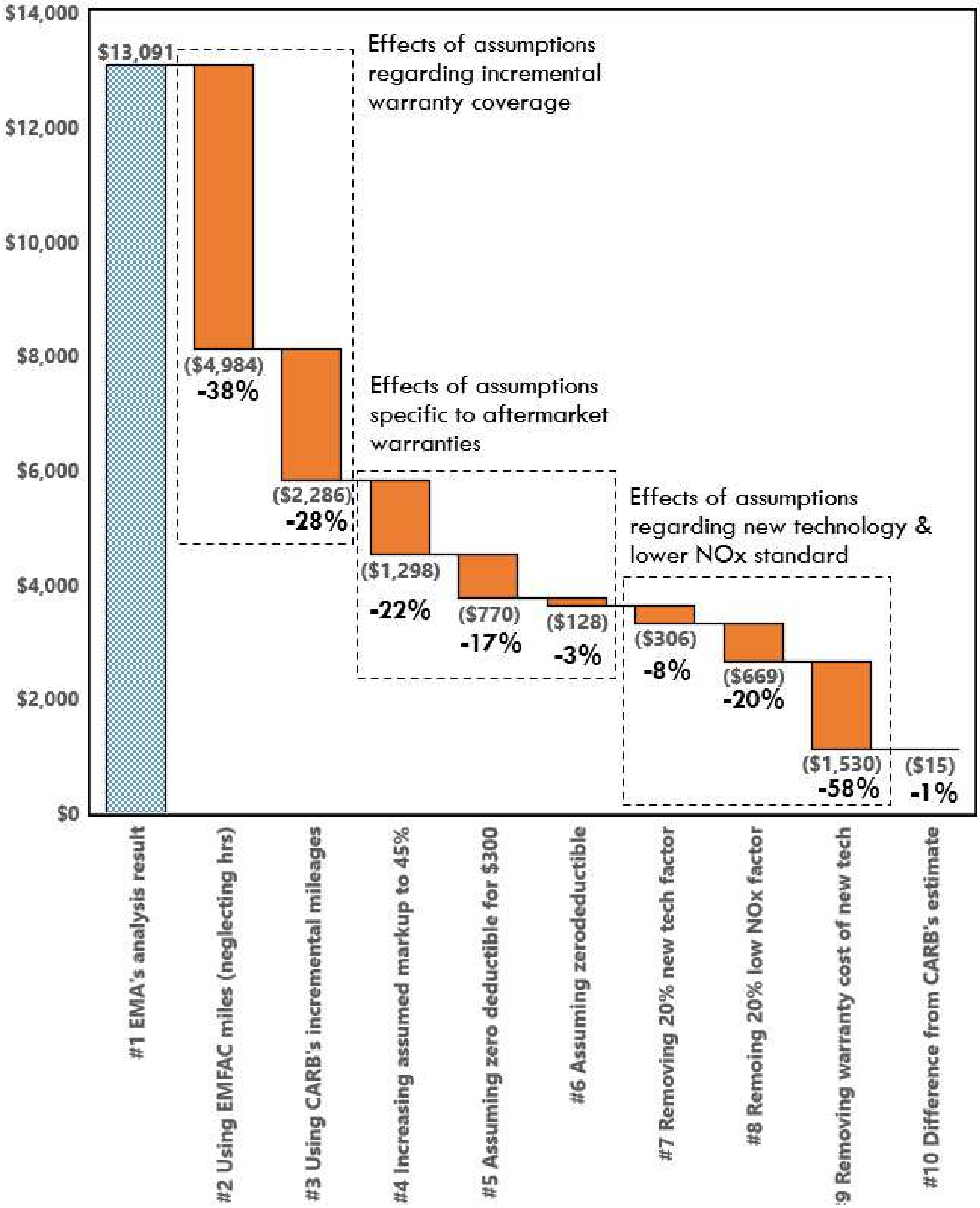


Figure I.1. Waterfall chart depicting the cumulative effects of different assumptions on EMA's warranty cost estimate based on aftermarket warranty price information. The percentage values correspond to the relative changes compared to the previous scenario.

II. Background

When CARB approved for adoption the Proposed Amendments to the Heavy-Duty Engine and Vehicle Omnibus Regulation and Associated Amendments (Omnibus Regulation) in August 2020, they directed CARB staff to participate in a Warranty Cost Study with industry stakeholders. The Board's purpose for conducting this study was to better understand the warranty cost differences between CARB staff's estimates and those estimates provided by industry stakeholders (reference Appendix A for the Board transcript). The study, carried out from October 2020 to June 2021, focused on mitigating the industry's concerns about the uncertainties of increasing warranty costs associated with the Omnibus Regulation for heavy-duty engines/vehicles. This report presents the outcomes of the Warranty Cost Study led by CARB staff in collaboration with industry stakeholders. All members of the work group were given an opportunity to review and comment on the contents of this report. However, ultimately this report represents CARB staff's findings, and not necessarily a group consensus.

In the June 2018 board hearing, CARB staff proposed amendments to warranty requirements effective from MY 2022, which was intended as the first step of the "Two-Step" rulemaking approach (CARB, 2018), and therefore is termed as "Step 1 Warranty." In the August 2020 board hearing, the Board approved for adoption CARB staff's proposal for "Step 2 Warranty" amendments which will become effective in MY 2027 and MY 2031. This was part of the Omnibus Regulation that comprehensively overhauled a variety of requirements for heavy-duty vehicles and engines including the emission standards, useful life, and warranty periods (CARB, 2020). For simplicity, a summary of the current and amended requirements for HHDD engines/Class 8 GVWR > 33,000 pounds (lbs) are shown in Table II.1. The requirements for other weight classes and for Otto-cycle engines/vehicles are not shown but are available in the staff reports (CARB, 2018; 2020).

Table II.1. Warranty periods, useful life, and NOx standards for HHDD engines / Class 8 GVWR > 33,000 lbs.

MYs	Warranty (miles)	Useful Life (miles)	NOx Standards		
			FTP/RMC (g/bhp-hr)	LLC (g/bhp-hr)	Idling (g/hr)
Current	100,000 5 years 3,000 hours	435,000 10 years 22,000 hours	0.20	-	30
2022	350,000 5 years				
2024			0.050	0.20	10
2027	450,000 7 years 22,000 hours	600,000 11 years 30,000 hours	0.020 @ 435,000 miles 0.035 @ 600,000 miles	0.050 @ 435,000 miles 0.090 @ 600,000 miles	5
2031	600,000 10 years 30,000 hours	800,000 12 years 40,000 hours	0.020 @ 435,000 miles 0.040 @ 800,000 miles	0.050 @ 435,000 miles 0.100 @ 800,000 miles	

One of the concerns raised by EMA during the Omnibus Regulation rulemaking process was the uncertainty of the increase in warranty costs in MY 2027 and 2031 when the NOx emission standards, useful life, and warranty periods become more stringent simultaneously. There were significant differences between the estimates of the warranty costs made by CARB, National Renewable Energy Laboratory (NREL), and America's Commercial Transportation (ACT) Research Co. Therefore, staff engaged with stakeholders and conducted a warranty cost study in response to the industry's concern regarding the warranty costs. The warranty cost study resulted in an analysis of three warranty cost methodologies and assumptions and provides information for the industry to assess costs for future planning purposes. The analysis shows that the discrepancies between different estimates mostly originate from different assumptions regarding the warranty coverage baseline (e.g., whether to account for voluntary extended warranties), warranty coverage endpoint (e.g., how to treat low-speed vehicles), and impact of the lower NOx standards (e.g., infant mortality). The results of the study may help the industry to better plan for complying with the Omnibus Regulation and mitigate the uncertainty that manufacturers and suppliers may have regarding the costs for the longer warranty periods under first and subsequent vehicle ownership.

III. Study Participants and Goals

CARB staff took the lead and formed a work group comprised of representatives from Cummins, MECA, and MEMA. The work group held a kick-off meeting on October 5, 2020 and agreed to hold biweekly meetings over a nine-month period and develop goals. The working group collaboratively established the following study goals, which are addressed in the subsequent chapters of this report:

1) Work collaboratively to better understand all the assumptions made and all of the differences in the various warranty cost analysis methods. (See Chapter IV below.)
2) Gather available data for heavy-duty vehicles to quantify the residual warranty value to the second and subsequent owners. (See Chapter V below.)
3) Gather available data on usage patterns and duty cycles from the second and subsequent owners of vehicles used in a variety of applications to assess wear characteristics. (See Chapter VI below.)
4) Make a plan for gathering and sharing data between original equipment manufacturers (OEMs) and emission control component suppliers as new technologies to meet MY 2024 and MY 2027 standards are rolled out. (See Chapter VII below.)
5) Facilitate discussions between OEMs and emission control component suppliers beyond the current 100,000 mile warranty period. (See Chapter VIII below.)
6) Review the results and the suggested next steps from the study. (See Chapter IX below.)

Subsequently, additional participants from EMA and ATA joined the work group. The work group met a total of 16 times over the nine-month period. This report represents CARB staff's findings related to each goal.

IV. Goal #1: Work collaboratively to better understand all the assumptions made and all of the differences in the various warranty cost analysis methods.

To address this goal, the work group improved the understanding of why there were large discrepancies between CARB's and other's warranty cost estimates. The discrepancies stem from the philosophical differences in what should be the baseline and what warranty should cover. CARB's method considered all vehicle owners including those who would be affected less by the rulemaking. Also, CARB staff assumed that the more rigorous heavy-duty engine durability demonstration program of the Omnibus Regulation would help ensure that parts will be designed to be more durable. Therefore, warranty was assumed to only cover defects, as intended, rather than covering failures of parts that were not designed properly to meet lower emission standards and useful life requirements. CARB's method shifts the future repair cost to where it is intended, i.e., with OEMs designing emission durable components. On the other hand, EMA's analysis method focused on those who did not already have extended warranty (and who thus would be affected more by the rulemaking) and assumed higher repair costs as lower NOx emission standards and useful life requirements would be phased in. When the analysis was limited to Step 1 warranty (no change in technology) and the effects of voluntary extended warranties were removed by estimating the warranty costs "per miles covered," CARB and OEM's MY 2022 warranty costs reasonably agreed as discussed below. Therefore, CARB staff concluded that its method was reasonable.

This section describes the warranty cost estimation methods used by CARB (CARB, 2018; 2020), NREL (NREL, 2020), and ACT (EMA, 2020), as well as EMA's additional analysis presented as a part of the warranty cost study. For simplicity, the discussion in this section focuses on Heavy Heavy-Duty Vehicles (HHDV) (>33,000 lbs. GVWR) or class 8 diesel vehicles unless noted otherwise.

A. CARB's method

1. Summary of CARB's method for Step 1 and Step 2 warranties

CARB estimated the incremental warranty cost as the summation of the increase in emission-related repair costs and finance costs. The baseline repair costs were estimated using the most recent five years of the unscreened warranty claim data reported through CARB's EWIR program. To calculate the relative increase in usage because of longer years/hours/miles limitations, CARB's EMFAC model simulations were used to calculate the miles covered under warranty, which were often less than the regulatory warranty mileage because of the years or hours limitations. The relative increases in the repair costs were calculated using the increase in weighted average miles covered under warranty due to the rulemaking. The additional cost due to linking warranty to the MIL was also accounted for. Finally, the finance cost for a five-year loan with a six percent interest rate was added to calculate the incremental warranty cost. The procedure is summarized in equation IV.1 as follows:

$$[\,\Delta\, warranty\ cost] = [Baseline\ repair\ cost] \times \frac{[Projected\ miles\ covered]-[Baseline\ miles\ covered]}{[Baseline\ miles\ covered]} + [MIL\ cost] + \ [Finance\ cost].$$

(Equation IV.1)

The major assumptions of CARB's method include the following:

a. The baseline repair costs represent the average repair cost currently incurred by all relevant vehicles in California.
b. The repair cost is proportional to usage (miles or hours) in the future. The future repair cost includes the repair cost of additional emission-related components meeting the lower NOx standards due to continuous improvements in existing technology by manufacturers.
c. The average miles covered under warranty includes the coverages of optional longer warranties either as OEM-offered extended warranties or aftermarket warranties.

In 2018, CARB approved adoption of longer emission warranty requirements for heavy-duty diesel engines that will take effect with MY 2022. These amendments are known as the Step 1 warranty amendments. The Omnibus Regulation includes further lengthening of the emission warranty requirements beginning with MY 2027 that are known as the Step 2 warranty amendments. This section describes the methods used for Step 1 and Step 2 warranty amendments separately.

2. Step 1 Warranty Method

a) Baseline repair costs

CARB staff estimated the current baseline repair costs for emission-related components over a five-year period. Actual five-year warranty claim data for MY 2012 was obtained from EWIRs provided by manufacturers and shown in Table IV.A.1. CARB staff estimated repair costs for individual engines and aftertreatment components by analyzing repair shop data and having discussions with manufacturers and service providers.

Table IV.A.1. Estimated Current Warranty Repair Rates and Costs for HHDVs (2017$) (Step 1 Initial Statement of Reasons (ISOR) Appendix C Table 7)

Part	Total Claims	Claim %	Avg. Repair Cost	Weighted Avg. Repair Cost
Diesel Particulate Filter (DPF)	107	1.1%	$2,600	$28.60
DPF Doser	699	7.1%	$500	$35.50
Diesel Oxidation Catalyst (DOC)	153	1.6%	$3,800	$60.80
Exhaust Gas Recirculation (EGR) Valve	1,114	11.3%	$1,200	$135.60
EGR Cooler	1,647	16.8%	$3,100	$520.80
Injector	1,037	10.6%	$1,900	$201.40
NOx Sensor	876	8.9%	$670	$59.63
Selective Catalytic Reduction (SCR)	777	7.9%	$5,371	$424.31
Turbo	808	8.2%	$5,100	$418.20
Other Sensors	1,315	13.4%	$670	$89.78
Exhaust Manifold	87	0.9%	$850	$7.65
Fuel System	472	4.8%	$2,000	$96.00
Engine Control Module (ECM)	1,200	12.2%	$1,725	$210.45
Total:	10,292	104.8%	--	**$2,289**

b) Baseline miles covered under warranty

To estimate the baseline miles covered under warranty, CARB considered the current warranty purchase practice for optional warranties longer than the 100,000 mile minimum currently required. Table IV.A.2 below shows the current and future purchase practices of longer warranties for HHDV assumed in Step 1 Warranty. The current percentages are based on the survey conducted by the Sacramento Institute for Social Research (ISR) (ISR, 2017) at CSUS under a contract with CARB. CARB staff assumed that those who currently purchase a longer warranty will continue to do so in the future. For example, 40 percent of owners who purchased a 500,000 miles warranty will continue to do so until the regulatory mileage requirement reaches 600,000 miles in MY 2031.

Table IV.A.2. Current and future warranty purchase practice for HHDV assumed in Step 1 Warranty

MYs	Regulatory requirements (% of vehicle population)	Assumed purchase of longer warranty (% of vehicle population)
Current	100,000 miles 5 years 3,000 hours (15%)	250,000 miles, 5 years (45%) 500,000 miles, 5 years (40%)
2022	350,000 miles 5 years (60%)	500,000, miles 5 years (40%)
2027	450,000 miles 7 years 22,000 hours (60%)	500,000, miles 7 years 22,000 hours (40%)
2031	600,000 miles 10 years 30,000 hours (100%)	-

A simple weighted average of the current warranty miles would result in 327,500 miles (i.e., 100,000 x 0.15 + 250,000 x 0.45 + 500,000 x 0.4). However, this value is greater than the miles covered under warranty because some vehicles would reach the years (or hours) limitation before mileage. To account for the effect of a 5-year limitation, the miles driven during the 5 year period were calculated for each vehicle category in the EMFAC model. The values for HHDV are shown in Table IV.A.3. Since most vehicles exhaust their warranties either by exceeding the mileage or year threshold, the 3,000-hour limit was assumed to be negligible and therefore excluded from Table IV.A.3.

The shaded cells in Table IV.A.3 correspond to the limiting factors (year vs. mileage) of the miles covered under warranty. The descriptions of EMFAC vehicle categories are shown in Table IV.A.4. For example, a T7 Public (Heavy-Heavy Duty Diesel Public Fleet Truck) accumulates 50,000 miles at the end of five years, and therefore the miles covered under warranty is 50,000 miles, not 100,000 miles. Over the entire EMFAC HHDV fleet, the 5-year limitation results in the weighted average miles covered under warranty averaging to 316,010 miles. Of note, this 316,010 miles is over three times the minimum warranty mileage currently required by today's regulation (i.e., 100,000 miles) indicating vehicle owners already voluntarily purchase warranties much longer than the minimum CARB requires. The data in Table IV.A.3 are illustrated in Figure IV.A.1.

Table IV.A.3. Current miles covered under warranty for EMFAC HHDV categories (adapted from Step 1 ISOR Appendix C Table 2)

5 Years/100,000 Miles				
	Population %	5 Year Odometer Mileage	Estimated Length of Warranty	Miles Covered Under Warranty
T7 Public	48.33%	50,000	100,000	50,000
T7 SWCV	33.07%	100,000	100,000	100,000
T7 Utility	3.13%	47,000	100,000	47,000
T7 Single Construction*	15.47%	212,000	100,000	100,000
			Weighted average miles covered for 15%	74,173
5 Years/250,000 Miles				
	Population %	5 Year Odometer Mileage	Estimated Length of Warranty	Miles Covered Under Warranty
Motor Coach	2.16%	353,000	250,000	250,000
T7 Ag	0.04%	299,000	250,000	250,000
T7 Single	23.96%	212,000	250,000	212,000
T7 Single Construction*	10.36%	212,000	250,000	212,000
T7 Tractor*	50.27%	489,000	250,000	250,000
T7 Tractor Construction	13.22%	489,000	250,000	250,000
			Weighted average miles covered for 45%	236,962
5 Years/500,000 Miles				
	Population %	5 Year Odometer Mileage	Estimated Length of Warranty	Miles Covered Under Warranty
T7 CAIRP	56.35%	585,000	500,000	500,000
T7 CAIRP Construction	3.90%	585,000	500,000	500,000
T7 Other Port	1.60%	489,000	500,000	489,000
T7 POAK	5.83%	489,000	500,000	489,000
T7 POLA	13.85%	489,000	500,000	489,000
T7 Tractor*	18.48%	489,000	500,000	489,000
			Weighted average miles covered for 40%	495,628
			Weighted average	**316,010**
*Vehicle type is segregated into two warranty classes to align projected extended warranty purchases.				

Table IV.A.4. EMFAC vehicle classes

EMFAC Vehicle Category	Description
T7 Ag	Heavy-Heavy Duty Diesel Agriculture Truck
T7 CAIRP	Heavy-Heavy Duty Diesel CA International Registration Plan Truck
T7 CAIRP construction	Heavy-Heavy Duty Diesel CA International Registration Plan Construction Truck
T7 other port	Heavy-Heavy Duty Diesel Drayage Truck at Other Facilities
T7 POAK	Heavy-Heavy Duty Diesel Drayage Truck in Bay Area
T7 POLA	Heavy-Heavy Duty Diesel Drayage Truck near South Coast
T7 Public	Heavy-Heavy Duty Diesel Public Fleet Truck
T7 Single	Heavy-Heavy Duty Diesel Single Unit Truck
T7 single construction	Heavy-Heavy Duty Diesel Single Unit Construction Truck
T7 SWCV	Heavy-Heavy Duty Diesel Solid Waste Collection Truck
T7 tractor	Heavy-Heavy Duty Diesel Tractor Truck
T7 tractor construction	Heavy-Heavy Duty Diesel Tractor Construction Truck
T7 utility	Heavy-Heavy Duty Diesel Utility Fleet Truck
UBUS	Urban Buses
Motor Coach	Motor Coach

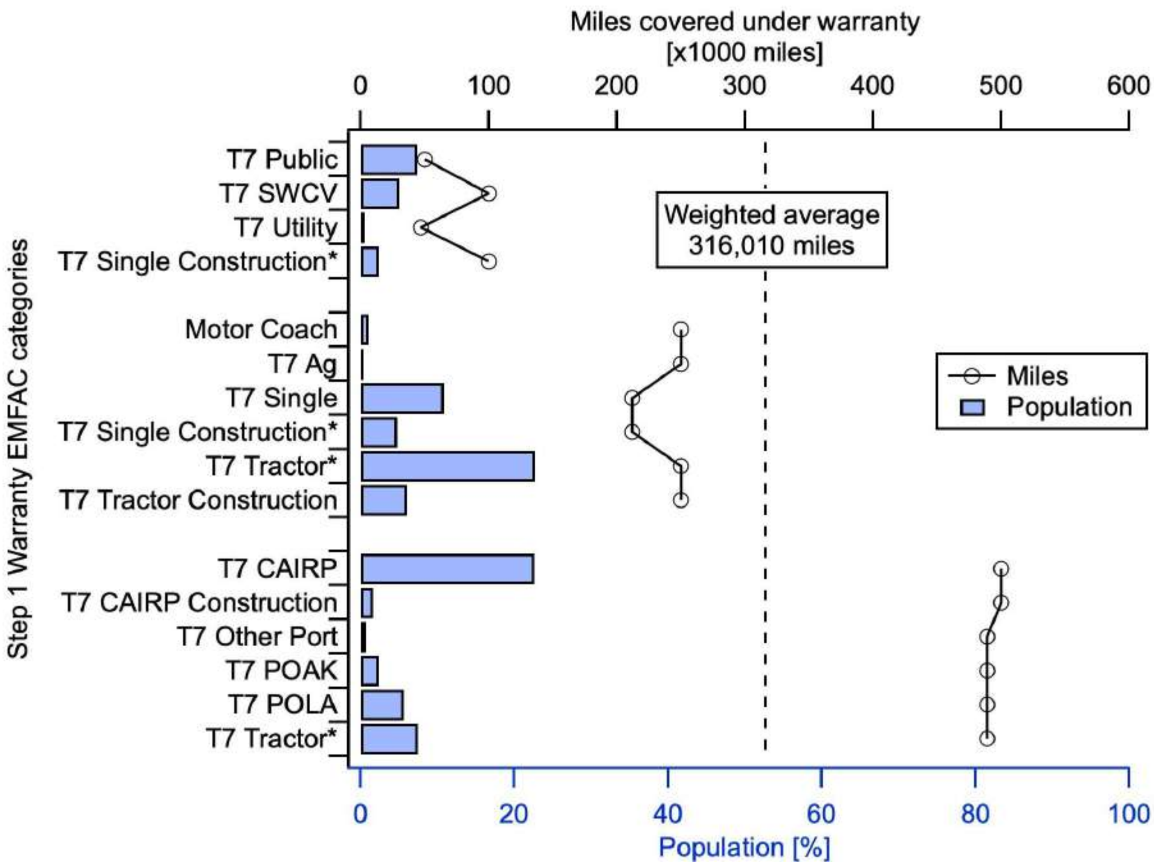


Figure IV.A.1. Illustration of the current miles covered under warranty for EMFAC HHDV categories

c) **Projected miles covered under Step 1 Warranty (MY 2022)**

As the regulatory warranty coverage extends in MY 2022, projected miles covered under warranty will increase. However, again, the projected miles covered under warranty will not be equal to the simple weighted average of warranty mileages. A simple weighted average would be 350,000 x 0.6 + 500,000 x 0.4 = 410,000 miles. To account for the effect of the 5-year limitation, the miles driven for 5 years were calculated for each vehicle category in the EMFAC model. The values for HHDV are shown in Table IV.A.5. The population-based weighted average after accounting for the 5-year limitation is 348,172 miles, significantly less than 410,000 miles simply calculated by the warranty miles only.

Table IV.A.5. Projected miles covered under Step 1 Warranty (MY 2022) for EMFAC HHDV categories (adapted from Step 1 ISOR Appendix C Table 14)

5 Years/350,000 Miles				
	Population %	5 Year Odometer Mileage	Estimated Length of Warranty	Miles Covered Under Warranty
T7 Public	12.08%	50,000	350,000	50,000
T7 SWCV	8.27%	100,000	350,000	100,000
T7 Utility	0.78%	47,000	350,000	47,000
T7 Single Construction	11.63%	212,000	350,000	212,000
Motor Coach	1.62%	353,000	350,000	350,000
T7 Ag	0.03%	299,000	350,000	299,000
T7 Single	17.97%	212,000	350,000	212,000
T7 Tractor*	37.68%	489,000	350,000	350,000
T7 Tractor Construction	9.92%	489,000	350,000	350,000
Weighted average miles covered for 60%				249,787
5 Years/500,000 Miles				
	Population %	5 Year Odometer Mileage	Estimated Length of Warranty	Miles Covered Under Warranty
T7 CAIRP	56.35%	585,000	500,000	500,000
T7 CAIRP Construction	3.90%	585,000	500,000	500,000
T7 Other Port	1.60%	489,000	500,000	489,000
T7 POAK	5.83%	489,000	500,000	489,000
T7 POLA	13.85%	489,000	500,000	489,000
T7 Tractor*	18.50%	489,000	500,000	489,000
Weighted average miles covered for 40%				495,750
Weighted average				**348,172**
*Vehicle type is segregated into two warranty classes to align projected extended warranty				

d) MIL-related costs for Step 1 Warranty

Since the Step 1 Warranty provisions enhanced and clarified the link between warranty coverage and any component that can lead to illumination of a MIL (i.e., linking on-board diagnostics (OBD) to warranty), more individual failure events will be honored under the warranty. The additional cost of components indirectly related to emission control via MIL is shown in Table IV.A.6 and is based on EWIR data which shows that claims from these additional components are all less than one percent. The increase in cost due to linking OBD to warranty is estimated to be $7.33.

Table IV.A.6. Estimated HHDV warranty repair rates and costs for additional components due to linking HD OBD to heavy-duty warranty (2017$) (Step 1 ISOR Appendix C Table 19)

Component	Avg. Repair Cost	Claim %	Weighted Avg. Repair Cost
Accelerator pedal position (sensor)	$695	0.02%	$0.16
Vehicle speed sensor	$278	0.57%	$1.58
Missing VIN - reflash ECU/ECM	$400	0.14%	$0.57
Battery voltage - wire replacement	$470	0.02%	$0.11
Battery voltage - battery replacement	$290	0.02%	$0.07
J1939/J1979 data link	$1,725	0.11%	$1.92
Thermostat	$230	0.07%	$0.16
Coolant level sensor	$245	0.05%	$0.12
Oil pressure sensor	$220	0.60%	$1.32
Crankcase pressure sensor	$148	0.78%	$1.16
Intake air heater	$715	0.02%	$0.17
Total:	-	-	**$7.33**

e) Projected cost of Step 1 Warranty

Based on the current average mileage (316,010 miles), baseline repair cost ($2,289), the projected average mileage in MY 2022 (348,172 miles), the projected repair cost of Step 1 Warranty was estimated to be $233. With the MIL-related cost ($7), the total repair cost was $240. Finally, additional finance costs for a five-year loan with a 6 percent interest rate were added to the repair cost. The cost of Step 1 Warranty was estimated to be $285 without markup and $413 with a 45 percent markup as shown in Table IV.A.7.

Table IV.A.7. Summary of Step 1 Warranty cost

	Baseline	**MY2022**
Mileage covered under warranty	316,010	348,172
Repair Cost	$2,289[a]	$2,522
Incremental repair cost	-	$233
Cost of additional MIL-related repairs	-	$7
Finance cost[b]	-	$45
Total Step 1 warranty cost (without markup)	-	**$285**
Total Step 1 warranty cost (with 45% markup)	-	$413

a. Repair cost estimated using 5-year data for MY2012 engines.

b. Six percent, five-year loan

3. Step 2 Warranty

CARB's Step 2 warranty cost estimate was lower than the others. This is because CARB's method considered all vehicle owners including those who would be affected less by the rulemaking (i.e., those who already had extended warranty, and those who will reach the operation-hour limit first). CARB also assumed parts would be more durable to meet the durability demonstration program requirements of the Omnibus Regulation as discussed below.

CARB staff's cost estimation method of Step 2 Warranty was analogous to that of Step 1 Warranty, with the exception that staff simplified how baseline mileage was attributed to various vehicle categories. It is important to note that Step 2 Warranty introduced additional hour requirements (22,000 hours in 2027; 30,000 hours in 2031) that further reduce the average miles covered under warranty.

a) **Baseline repair cost**

In Step 2 Warranty, the repair cost analysis was further expanded to include additional components using more current data than what was available in the Step 1 Warranty rulemaking. Additional categories allowed for a more accurate cost estimate. The total baseline repair cost increased to $2,400 as shown in Table IV.A.8. The updated repair cost is $111 more than the Step 1 Warranty's current (2017$) repair cost of $2,289.

Table IV.A.8. 2013 Model year warranty claim rates and costs for the HHDV category (2018$) (Omnibus Regulation ISOR Appendix C-3, Table I.17)

Component	Total Claims[a]	Warranty Claims Rate	Average Repair Cost	Weighted Average Repair Cost
CATALYST	0	0.00%	$2,500	$0.00
DOC	893	8.10%	$3,800	$307.88
DPF	118	1.10%	$2,600	$27.84
Engine Control Unit (ECU)	653	5.90%	$1,725	$102.20
SCR	138	1.30%	$5,371	$67.25
DEF DOSER	1,010	9.20%	$1,178	$107.95
DPF DOSER	778	7.10%	$1,178	$83.15
EGR COOLER	1,059	9.60%	$3,100	$297.85
EGR VALVE	358	3.20%	$1,200	$38.98
FUEL INJECTOR	659	6.00%	$2,208	$132.02
TURBOCHARGER	1,082	9.80%	$5,100	$500.65
BLOWBY FILTER	0	0.00%	$150	$0.00
BOOST CONTROL VALVE	12	0.10%	$450	$0.49
CHARGE AIR COOLER	2	0.00%	$3,000	$0.54
CHARGE AIR DUCT	28	0.30%	$300	$0.76
CLAMP	8	0.10%	$50	$0.04
CRANKCASE SEPARATOR	22	0.20%	$1,029	$2.05
CYLINDER HEAD	26	0.20%	$5,000	$11.79
DEF PUMP	454	4.10%	$1,445	$59.52
DEF TANK	27	0.20%	$1,000	$2.45
ECU REPROGRAM	3,246	29.50%	$400	$117.80
ELECTRICAL HARNESS	122	1.10%	$277	$3.07
EXHAUST MANIFOLD	369	3.30%	$2,500	$83.70
EXHAUST VALVE	81	0.70%	$3,500	$25.72
FUEL LINE	6	0.10%	$1,362	$0.74
FUEL PUMP	370	3.40%	$1,624	$54.52
FUEL TANK	0	0.00%	$2,000	$0.00
GASKET	111	1.00%	$100	$1.01
IGNITION CONTROL MODULE	282	2.60%	$550	$14.07
INTAKE MANIFOLD	2	0.00%	$2,500	$0.45
NOx SENSOR	1,677	15.20%	$670	$101.94
OIL PUMP	35	0.30%	$1,293	$4.11
OIL RAIL	16	0.10%	$1,638	$2.38
OIL SEPARATOR	879	8.00%	$500	$39.87
OTHER SENSORS	3,206	29.10%	$670	$194.88
PRESS CONTROL VALVE	41	0.40%	$500	$1.86
RUBBER HOSE	25	0.20%	$250	$0.57
THROTTLE VALVE	138	1.30%	$805	$10.08
VACUUM PUMP	0	0.00%	$550	$0.00
TOTAL	**17,933**	**162.70%**	**--**	**$2,400**

[a] Note that the total claims values shown are for HHDV and urban buses. This was done to remain consistent with certification requirements that define an urban bus as a bus that is normally powered by a heavy heavy-duty engine and weighs greater than 33,000 pounds GVWR

CARB staff estimated the repair costs associated with the indirect OBD components to be $16 for HHDV.

b) Baseline miles covered under warranty (MY 2022)

The baseline mileage assumed the warranty purchase practice after the beginning of Step 1 Warranty in MY 2022. CARB staff simplified the assumed EMFAC vehicle population distribution in the 350,000 and 500,000-mile category. As discussed in section IV.A.2.b, CARB staff determined the current warranty purchase practice (i.e., 40 percent of HHDV have 500,000 miles warranty; 45 percent 250,000 miles; 15 percent 100,000 miles) based on CSUS survey data (ISR, 2017). In Step 1 Warranty rulemaking, CARB staff assumed that owners of vehicle subcategories that would accumulate high mileages tended to purchase longer warranties voluntarily (see section IV.A.2.b). In Step 2 Warranty rulemaking, CARB staff removed the assumption and applied the same warranty purchasing business practices for all the vehicle subcategories because data to determine who would purchase the extended coverage and who would rely on the regulatory warranty was unavailable. Therefore, for the Step 2 baseline, vehicle population percent distributions were assumed to be identical for 60 percent covered to 350,000 mile (Step 1 Warranty requirement) and for 40 percent covered to 500,000 miles voluntarily. The revised assumption was more conservative (i.e., higher cost) because 60 percent of high-mileage vehicles (e.g., T7 CAIRP) were assumed to only have regulatory warranties. This explains why the Step 2 baseline mileage (288,692 miles) is less than the projected Step 1 mileage (348,172 miles) (section IV.A.2.c).

Table IV.A.9. Estimated baseline miles covered under Step 1 Warranty (MY 2022) for EMFAC HHDV categories (adapted from Omnibus Regulation ISOR Appendix C-3 Table I.11)

60% covered to 350,000 miles				
Vehicle Subcategory	**Population %**	**5 Year Mileage**	**Warranty Mileage**	**Miles Covered Under Warranty**
Motor Coach	1.31%	352,917	350,000	350,000
T7 CAIRP	13.15%	584,953	350,000	350,000
T7 CAIRP Construction	1.19%	584,953	350,000	350,000
T7 Other port	0.70%	488,987	350,000	350,000
T7 POAK	2.57%	488,987	350,000	350,000
T7 POLA	7.74%	488,987	350,000	350,000
T7 Public	11.01%	49,896	350,000	49,896
T7 Single	11.79%	211,768	350,000	211,768
T7 Single Construction	8.29%	211,768	350,000	211,768
T7 SWCV	7.18%	100,325	350,000	100,325
T7 Tractor	21.75%	488,987	350,000	350,000
T7 Tractor Construction	5.54%	488,987	350,000	350,000
T7 Utility	0.27%	46,656	350,000	46,656
UBUS	7.50%	194,564	350,000	194,564
Weighted Average Miles Covered for 60%				258,763
40% covered to 500,000 miles				
Vehicle Subcategory	**Population %**	**5 Year Mileage**	**Warranty Mileage**	**Miles Covered Under Warranty**
Motor Coach	1.31%	352,917	500,000	352,917
T7 CAIRP	13.15%	584,953	500,000	500,000
T7 CAIRP Construction	1.19%	584,953	500,000	500,000
T7 Other Port	0.70%	488,987	500,000	488,987
T7 POAK	2.57%	488,987	500,000	488,987
T7 POLA	7.74%	488,987	500,000	488,987
T7 Public	11.01%	49,896	500,000	49,896
T7 Single	11.79%	211,768	500,000	211,768
T7 Single Construction	8.29%	211,768	500,000	211,768
T7 SWCV	7.18%	100,325	500,000	100,325
T7 Tractor	21.75%	488,987	500,000	488,987
T7 Tractor Construction	5.54%	488,987	500,000	488,987
T7 Utility	0.27%	46,656	500,000	46,656
UBUS	7.50%	194,564	500,000	194,564
Weighted Average Miles Covered for 40%				333,586
Overall Weighted Average Mileage Covered for HHDV				**288,692**

c) Projected miles covered under Step 2 Warranty (MY 2027 & 2031)

The projected miles covered under Step 2 Warranty were calculated in the same manner as described above. Table IV.A.10 shows the estimated miles in MY 2027-2030, and Table IV.A.11 is for MY 2031+. Step 2 Warranty introduced additional hour-limits that led to approximately 25 percent of vehicles reaching the hour-limit first both in MY 2027-2030 and MY 2031. In MY 2031, it was assumed that no vehicle owner purchased longer warranty beyond the regulatory requirements.

Table IV.A.10. Estimated miles covered under Step 2 Warranty (MY 2027-2030) for EMFAC HHDV categories (adapted from Omnibus Regulation ISOR Appendix C-3 Table I.26)

HHDV Warranty Mileage Estimates in MY 2027- 2030					
60% covered to 450,000 miles					
Vehicle Subcategory	**Population %**	**7-year mileage**	**22,000 hours equivalent miles**	**Warranty Mileage**	**Miles Covered Under Warranty**
Motor Coach	1.31%	462,917	903,665	450,000	450,000
T7 CAIRP	13.15%	731,451	903,665	450,000	450,000
T7 CAIRP Construction	1.19%	731,451	378,880	450,000	378,880
T7 Other port	0.70%	615,841	232,056	450,000	232,056
T7 POAK	2.57%	615,841	232,056	450,000	232,056
T7 POLA	7.74%	615,841	232,056	450,000	232,056
T7 Public	11.01%	65,448	443,133	450,000	65,448
T7 Single	11.79%	265,329	603,795	450,000	265,329
T7 Single Construction	8.29%	265,329	378,880	450,000	265,329
T7 SWCV	7.18%	131,595	240,933	450,000	131,595
T7 Tractor	21.75%	615,841	710,426	450,000	450,000
T7 Tractor Construction	5.54%	615,841	378,880	450,000	378,880
T7 Utility	0.27%	62,208	278,715	450,000	62,208
UBUS	7.50%	270,358	221,255	450,000	221,255
Weighted Average Miles Covered for 60%					**300,715**
40% covered to 500,000 miles					
Vehicle Subcategory	**Population %**	**7-year mileage**	**22,000 hours equivalent miles**	**Warranty Mileage**	**Miles Covered Under Warranty**
Motor Coach	1.31%	462,917	903,665	500,000	462,917
T7 CAIRP	13.15%	731,451	903,665	500,000	500,000
T7 CAIRP Construction	1.19%	731,451	378,880	500,000	378,880
T7 Other Port	0.70%	615,841	232,056	500,000	232,056
T7 POAK	2.57%	615,841	232,056	500,000	232,056
T7 POLA	7.74%	615,841	232,056	500,000	232,056
T7 Public	11.01%	65,448	443,133	500,000	65,448
T7 Single	11.79%	265,329	603,795	500,000	265,329
T7 Single Construction	8.29%	265,329	378,880	500,000	265,329
T7 SWCV	7.18%	131,595	240,933	500,000	131,595
T7 Tractor	21.75%	615,841	710,426	500,000	500,000
T7 Tractor Construction	5.54%	615,841	378,880	500,000	378,880
T7 Utility	0.27%	62,208	278,715	500,000	62,208
UBUS	7.50%	270,358	221,255	500,000	221,255
Weighted Average Miles Covered for 40%					**318,336**
Overall Weighted Average Mileage Covered for HHDV MY 2027- 2030: 307,763 miles					

Table IV.A.11. Estimated miles covered under Step 2 Warranty (MY 2031+) for EMFAC HHDV categories (adapted from Omnibus Regulation ISOR Appendix C-3 Table I.27)

HHDV Warranty Mileage Estimates in MY 2031 and subsequent					
100% covered to 600,000 miles					
Vehicle Subcategory	**Population %**	**10-year mileage**	**30,000 hours equivalent miles**	**Warranty Mileage**	**Miles Covered Under Warranty**
Motor Coach	1.31%	611,967	1,232,271	600,000	600,000
T7 CAIRP	13.15%	800,000	1,232,271	600,000	600,000
T7 CAIRP Construction	1.19%	800,000	516,654	600,000	516,654
T7 Other port	0.70%	765,588	316,440	600,000	316,440
T7 POAK	2.57%	765,588	316,440	600,000	316,440
T7 POLA	7.74%	765,588	316,440	600,000	316,440
T7 Public	11.01%	88,776	604,272	600,000	88,776
T7 Single	11.79%	336,079	823,356	600,000	336,079
T7 Single Construction	8.29%	336,079	516,654	600,000	336,079
T7 SWCV	7.18%	178,500	328,544	600,000	178,500
T7 Tractor	21.75%	765,588	968,762	600,000	600,000
T7 Tractor Construction	5.54%	765,588	516,654	600,000	516,654
T7 Utility	0.27%	85,536	380,066	600,000	85,536
UBUS	7.50%	393,363	301,712	600,000	301,712
Weighted Average Mileage Covered for HHDV MY 2031 and subsequent: 399,843 miles					

Figure IV.A.2 below illustrates the data provided in Table IV.A.11.

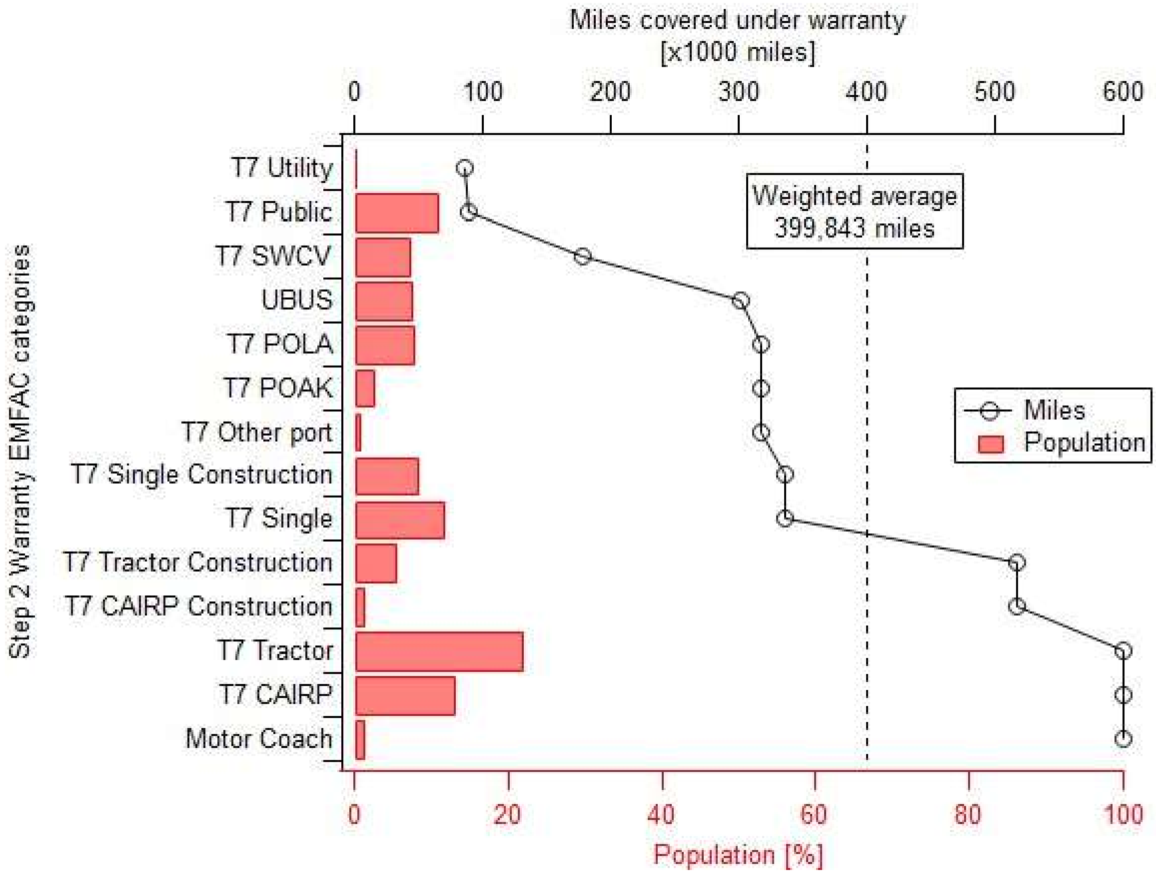


Figure IV.A.2. Illustration of the estimated miles covered under Step 2 Warranty (MY 2031+) for EMFAC HHDV categories

d) **Projected cost of Step 2 Warranty**

Finally, with the Step 2 Warranty baseline mileage (section IV.A.3.b), baseline repair cost (section IV.A.3.a), and projected mileages (section IV,A.3,c), the projected cost of Step 2 Warranty can be calculated. Table IV.A.12. summarizes the Step 2 Warranty costs, including the finance cost.

Table IV.A.12. Summary of Step 2 Warranty cost

	Baseline (MY2022)	MY2027	MY2031
Mileage	288,710[a]	307,763	399,843
Repair Cost	$2,416[b]	$2,576	$3,346
Incremental repair cost	-	$159	$771
Finance cost[c]	-	$30	$144
Total Step 2 warranty cost	-	-	**$1,104**

a. Baseline value differed from Step 1 because of different population % assumption
b. Repair cost estimated using five-year data reported for MY2013 engines
c. Six percent, five years loan on incremental repair costs

B. NREL's method

1. Summary of NREL's method

NREL estimated incremental cost (without any retail price markup) based on the survey responses from stakeholders including industry association groups, Tier 1 suppliers, and engine OEMs. NREL's Task 1 was to estimate the initial incremental costs of the technologies, while NREL's Task 2 considered the life-cycle cost assessment considering the aftertreatment technologies' effects on fuel consumption, diesel exhaust fluid (DEF) consumption, major overhaul intervals (full useful life estimates), manufacturing volume, and financial discount rates. In this report, CARB focused on the incremental warranty cost estimated in NREL's Task 1 since the life-cycle cost in Task 2 did not isolate the warranty cost.

The conditions assumed in the Task 1 second survey are summarized in Table IV.B.1. It should be noted that the useful life, warranty period, and the full useful-life NOx standard are more stringent than CARB's values because CARB staff had not finalized the proposed requirements at the time of NREL's study. As a result, the costs are significantly higher. Additionally, the details of the baseline were not specified; OEMs considered their current warranties, which varied between OEMs. The California-only production volume can result in higher warranty costs due to higher unit prices if California-specific parts with small production volumes are used. For this report, CARB focused on the 12-13 L average-cost diesel aftertreatment technology as it was the most similar to the setup implemented in Stage 3 demonstration program by the Southwest Research Institute (Sharp, 2021). The proposed average-cost diesel technology package consisted of a United States Environmental Protection Agency 2017 certification-compliant engine with a variable-geometry turbocharger, no turbo compounding, and an engine thermal management strategy and technology for cylinder deactivation. The average-cost aftertreatment system is illustrated in Figure IV.B.1.

Table IV.B.1. Conditions assumed in NREL's warranty cost estimation (Task 1 survey 2)

MY	2027
Useful life	1,000,000 miles / 15 years
Warranty period	800,000 / 12 years
NOx standard	0.02 g/bhp-hr
Baseline cost and warranty period	Current warranty offered by the OEMs (whatever that may be)
Production volume	California only
Engine displacement volume	6-7L, 12-13L
Technology packages	Low-cost, average-cost, high-cost packages

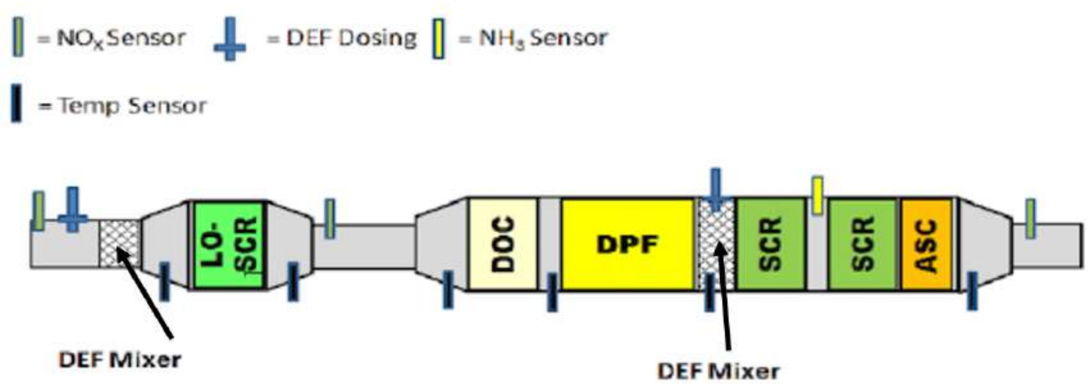


Figure IV.B.1. Schematic of proposed low- and average-cost diesel aftertreatment technology

2. Estimated cost

NREL's cost estimation for the potential average-cost 12-13 L diesel technology package is shown in Table IV.B.2. The average warranty incremental cost was $23,061, which was 21 times higher than CARB's Step 2 warranty cost ($1,104).

Table IV.B.2. Survey Responses for Potential Average-Cost Diesel Technology Package 12–13 L with Extended FUL, Extended Warranty, and California-Only Volumes (NREL report Table 18).

12–13 L	**Low**	**Avg.**	**High**
Cylinder Deactivation	$724	$1,176	$1,860
Other	$1,100	$1,100	$1,100
Total Engine Technology Cost	**$1,824**	**$2,276**	**$2,960**
LO-SCR	$736	$1,330	$2,450
DOC	$0	$144	$330
DPF	$0	$83	$191
SCR+ASC and DEF Dosing System	$500	$1,240	$1,892
OBD Sensors and Controllers (NO_x, NH_3, and Temp Sensors)	$476	$765	$997
Other	$300	$950	$1,600
Total Aftertreatment Technology Incremental Cost	**$2,012**	**$4,512**	**$7,460**
R&D Engineering Incremental Cost	$110	$357	$603
Certification Incremental Costs	$0	$7	$13
Warranty Incremental Costs	$7,840	$23,061[a]	$38,282
Total Indirect Incremental Costs to Manufacturer	**$7,950**	**$23,424**	**$38,898**
Total Incremental Cost Comparison	**$11,786**	**$30,212**	**$49,318**

a: CARB used this value for comparison in Table I.1.

NREL emphasized that the warranty incremental costs were based on an extremely small sample size of respondents, which may be biased high because of the OEMs' uncertainties regarding covering warranty for unfamiliar technology and much longer useful lives than today's useful lives. These warranty costs may be interpreted to represent "worst case" due to these uncertainties (NREL, 2020, page 50). While NREL did not know the method used by each OEM to determine their incremental warranty cost estimates, NREL listed the following potential reasons for the high warranty cost:

- **Failure uncertainty** – Because the OEMs will not perfectly estimate the probability of failure for their aftertreatment packages, they may charge more than needed initially to ensure they have enough capital to cover any future liabilities. This would be an amount in excess of what the vehicle owners would actually incur but would be expected to decrease over time as the failure rates on new technologies become known with more certainty.

- **Cost of capital** – The OEMs have higher costs of capital than individual vehicle owners. Thus, their cost to reserve funding to cover future warranty liabilities would be more than what a vehicle owner would realize in lifetime repair costs on average.
- **Soft costs** – The OEMs may have embedded additional "soft" costs into the cost estimate for the extended full useful life and extended warranty to account for costs associated with warranty administration (tracking warranty data, contacting vehicle owners, processing payments), legal liability (increased legal staffing in the event of fraud), and potentially others.
- **Customer relationships** – Some manufacturers may reduce the price of the aftertreatment package with extended warranty for some customers with long-standing relationships or high volumes of purchases. These discounts may then be offset with the "typical" MSRP aftertreatment price, which may be reflected as marketing-decision price distortions inflating the values reported to NREL's survey.

C. ACT Research's method

1. Summary of ACT Research's method

ACT Research (ACT) obtained industry input primarily consisting of confidential business information (CBI), and therefore specific technology solutions were not disclosed to CARB. Table IV.C.1 summarizes the conditions assumed in ACT's warranty cost estimation. Although the ACT report did not explicitly specify the warranty periods and NOx standard, the input from the work group indicated that they were 12 years /800,000 miles and 0.02 g/bhp-hr, which is significantly more stringent than CARB's 2031+ MY warranty requirements (see Table II.1). The mismatch resulted because their study was based on an earlier CARB staff proposal (CARB, 2019) versus the endpoints that were ultimately proposed and approved for adoption by the Board.

Table IV.C.1. Conditions assumed in ACT's warranty cost estimation

MY	2027 and 2031
Baseline warranty periods	2 years / 250,000 miles
Production volume	Nationwide and California only
Discount rate	2%, 3%, 7%, and Weighted Average Cost of Capital 10%

2. Estimated cost

Table IV.C.2 and Table IV.C.3 summarize the estimated incremental indirect cost to meet MY 2027 and MY 2031 standards assuming a 7 percent discount rate with California and national volumes, respectively. The costs for "Warranty on new technology" and "Warranty Step 2" combined were $7,227 for California-only production, which was 7 times higher than CARB's Step 2 warranty cost ($1,104).

Table IV.C.2. Summary of ACT's incremental indirect costs for HHDD at 7% discount rate (California volume)

Indirect Cost to Manufacturers	MY2027 from MY2018 baseline	MY2031 from MY2027 baseline	Sum
Research and development costs	$26,029	$169	$26,198
Warranty on new technology	$1,713	$0	$1,713
Warranty Step 2	$2,562	$2,952	$5,514
Useful life extension	$7,622	$6,947	$14,569
Compliance program costs	$2,023	$0	$2,023

Table IV.C.3. Summary of ACT's incremental indirect costs for HHDD at 7% discount rate (National volume)

Indirect Cost to Manufacturers	MY2027 from MY2018 baseline	MY2031 from MY2027 baseline	Sum
Research and development costs	$1,900	$9	$1,909
Warranty on new technology	$1,506	$0	$1,506
Warranty Step 2	$2,258	$2,663	$4,921
Useful life extension	$6,445	$5,524	$11,969
Compliance program costs	$125	$0	$125

D. EMA's analysis

1. Aggregated incremental costs of Step 1 warranty

As part of Goal #1, CARB staff described the cost estimation methodology used for Step 1 warranty in detail in several work group meetings. The work group members suggested that staff compare CARB staff's estimated Step 1 warranty cost (i.e., $285) with the average price increase for MY 2022 products as compiled by EMA. EMA gathered, aggregated, and averaged the available cost data of Step 1 warranty (email dated June 18, 2021) and reported that the incremental costs were approximately $3,750 for larger 15 L engines, $2,500 for 11-13 L engines, and $1,400 for medium heavy-duty (MHD) engines. The estimated average cost increases did not include OEM mark-ups or Federal Excise Tax (FET) impacts. CARB staff considered $2,500 for 11-13 L engines to be most relevant to this report because the warranty cost estimation by the National Renewable Energy Laboratory (NREL) for 12-13 L with approximately 475 horsepower (hp) was the representative HHDD engine platform (NREL, 2020). NREL stated that although they initially planned to survey costs for 12 L and 15 L engines for the HHDD category, industry requested NREL to consolidate engine platforms to make the burden of calculating incremental costs for surveys manageable. Industry agreed that 12-13 L represented the HHDD category based on the current trends of increased power density.

The difference between the Step 1 incremental cost reported by EMA (e.g., $2,500 for 11-13 L engine) and CARB's estimate ($285 for HHDV) is mostly due to the different assumptions regarding the incremental warranty coverage. As shown in Table IV.A.2, CARB considers that most owners voluntarily purchase longer warranties beyond the current regulatory requirements. Also, CARB used the EMFAC model to quantitatively determine the limiting factor of warranty requirements (miles, years, or hours) for each vehicle subcategory. Therefore, CARB estimated that when the regulatory warranty requirements extend from 100,000 miles/5 year/3000 hours to 350,000 miles/5 year for MY 2022-2023, the miles driven during the warranty periods will only increase by 32,100 miles (see section IV.A.2 for more details), as opposed to the apparent 250,000 miles that would increase from 100,000 to 350,000 miles.

Hypothetically speaking, if the OEMs used the same failure rates and the repair costs as CARB but assumed a 250,000 increase in miles covered under warranty (i.e., from 100,000 to 350,000 miles), as opposed to CARB's estimate of 32,100 miles, the estimated incremental warranty costs would be $2,219 (i.e., $285 * 250,000 miles/ 32,100 miles), an increase of a factor of eight. During CARB staff's interviews with OEMs, one indicated that their volume-weighted average of the incremental warranty cost for MY 2022 HHDD was approximately $2,000 (this price did not include OEM markup or financing), which indicated that on a per-mile basis, CARB and the OEM's MY 2022 warranty costs were in reasonable agreement. The apparent cost difference can be attributed to whether extended warranties purchased voluntarily should be included in the baseline. CARB staff believes it was reasonable to include them because it represented the status quo before the rulemaking. Furthermore, title 13, California Code of Regulation, section 2036(c) requires emission warranties to be no less than the basic mechanical warranty that the manufacturer provides (with or without additional charge) to the purchaser of the engine. Therefore, the extended basic mechanical warranties should be considered as the regulatory baseline.

2. EMA's analysis of aftermarket warranty price information

EMA carried out an alternative cost estimation of Step 2 warranty based on their analysis of confidential price information from a third-party aftermarket warranty provider. EMA used two different baselines: one using the OEM-offered base warranty (5 years / 250,000 miles) as the baseline and another using Step 1 Warranty (5 years / 350,000 miles) as the baseline. EMA assumed that the warranty endpoint was 10 years / 600,000 miles, neglecting the 30,000-hour limit. This section uses the latter analysis. However, CARB's Step 2 Warranty cost estimate included a 30,000-hour limit. To protect the confidentiality of the aftermarket warranty information, the details of specific warranty plans were removed. The major assumptions of EMA's calculation process are summarized below:

- The baseline is the Step 1 Warranty: 5 years / 350,000 miles.
- To calculate the incremental warranty cost between 5 years / 350,000 miles and 10 years / 600,000 miles, the cost for warranty for an additional 5 years and additional 250,000 miles needed to be estimated. EMA used confidential aftermarket warranty pricing information (including deductible costs) to calculate the incremental warranty cost. Since an exact match was not available in the available aftermarket warranty plans, EMA used the warranty price for 50 percent of 2 years /200,000 miles plan + 50 percent of 3 years / 300,000 miles plan, assuming mileage is the limiting factor determining the price.
- EMA made assumptions that aftermarket warranty prices would be marked up 20 percent for profit and vehicle owners pay deductible fees for a certain number of repairs. The incremental warranty cost was estimated to be $5,340.
- The lower NOx standards were assumed to lead to a 20 percent increase in repair cost because (1) the tighter control limits and OBD strategies drive higher OBD MIL-on frequency, (2) there are additional failures due to components that indirectly contribute to MIL-on, and (3) unit cost increases due to longer useful life.
- EMA assumed that the cost of the current emission-related components (ERCs) meeting the current federal requirements (US10 ERCs) was $10,000. The new ERCs for meeting MY 2027 standards was estimated to cost $4,580 (i.e., 46 percent of US10 ERCs cost) based on an on-going study contracted by EMA.

- When the new ERCs were included in the warranty coverage, the costs for the baseline warranty and the additional warranty both increased by 46 percent, assuming linearity between component costs and repair costs.
- New technology was assumed to experience 20 percent higher fail rates in the early years of production. For example, if a mature component has a 3 percent fail rate, the product will have a 3.6 percent fail rate in early years.

Using these assumptions, EMA calculated the incremental warranty cost in terms of the current technology package meeting the future lower NOx standard (US10, low NOx) and the new technology:

$$[\Delta\, warranty\ cost] = [\Delta\, warranty\ cost]_{US10,lowNOx} + [\Delta\, warranty\ cost]_{New}.$$

(Equation IV.2)

The incremental warranty cost for the current technology was affected by the assumed 20 percent low NOx factor:

$$[\Delta\, warranty\ cost]_{US10,lowNOx} = [Baseline\ warranty\ cost] * 0.2 + [\Delta\, warranty\ cost]_{US10} * 1.2,$$

(Equation IV.3)

whereas the incremental warranty cost for the new technology was assumed to be 46 percent of US10 warranty costs with the assumed 20 percent new technology factor:

$$[\Delta\, warranty\ cost]_{New} = ([Baseline\ warranty\ cost] + [\Delta\, warranty\ cost]_{US10}) * 0.46 * 1.2.$$

(Equation IV.4)

Using the equations above, EMA estimated the incremental warranty cost for the existing technology and the new technology would be $7,408 and $5,683, respectively, totaling $13,091, which is 12 times higher than CARB's Step 2 warranty cost estimate.

E. CARB's analysis of the difference between CARB and NREL/ACT Research/EMA's estimates

1. Major causes of the discrepancy

CARB staff evaluated the three warranty cost estimation methods provided by NREL, ACT Research, and EMA, and conducted a comparison and analysis of assumptions and costs. CARB staff believes that CARB's method is reasonable and defensible and has identified the following key areas where CARB and NREL/ACT Research/EMA have differing viewpoints.

a) Should optional warranties be included in the baseline?

To estimate the overall cost impact of the rulemaking, CARB's baseline warranty considered those owner/operators and fleets who voluntarily purchased optional warranties (e.g., 5 years / 500,000 miles) longer than the regulatory warranties since they would not be directly impacted by the rulemaking. ACT Research's cost estimate, on the other hand, considered 5 years / 250,000 miles as the baseline for the entire vehicle population. CARB's higher baseline correctly leads to the lower incremental costs. CARB's approach more accurately represents the average baseline in the entire state and therefore is more appropriate for the rulemaking.

b) How should warranty periods be quantified?

Since warranty coverage may be limited by years, hours, or miles, a challenge arose when comparing the coverage of two warranty periods with different ratios of years: hours: miles, especially when there was no hour limit in one case (e.g., MY 2022 vs. MY 2031). CARB's approach was to estimate the miles driven over each of the year- and hour-limitations to find the miles covered under warranty. For example, the regulatory warranty period in MY 2022 is 5 years / 350,000 miles and MY 2031 warranty period is 10 years / 600,000 miles / 30,000 hours. In terms of years alone, the warranty period increases by a factor of 2 (= 10/5) and in terms of miles a factor of 1.7 (= 600,000/350,000). However, when the hour limit is also considered using EMFAC simulations, the relative increase in coverage from MY 2022 to MY 2031 in terms of miles covered under warranty is only a factor of 1.4 (=399,843/288,692). CARB's small relative increase in warranty coverage contributed to its low-cost estimate. CARB's approach is the most transparent in terms of how years, miles, and hours are considered in quantifying the warranty coverage.

c) What is the cost of current warranties?

CARB staff estimated the baseline repair costs for individual engine and aftertreatment components by analyzing repair shop data and by having discussions with manufacturers and service providers and then considering the finance costs for a 5-year and 6 percent loan to the repair costs. EMA used aftermarket warranty prices as the basis for estimating the incremental warranty cost for the current ERCs up to 10 years / 600,000 miles. No details regarding cost estimation methods were available in the NREL and ACT reports as they were CBI.

CARB staff thinks its approach is reasonable given the unique circumstances of aftermarket warranties. For instance, aftermarket warranty providers may need to obtain parts from OEMs. Also, their customers may be disproportionately high-mileage drivers who accumulate mileages well over the current full useful life and expect frequent failures (because such drivers would be those who would most likely choose to buy an aftermarket warranty). Also, there is no basis for the 20 percent markup assumed in EMA's analysis of the aftermarket warranty price.

d) **Will the lower NOx standards and new technology increase warranty costs?**

EMA's analysis assumed that the lower NOx standards would lead to an approximately 20 percent increase in warranty cost and the introduction of new technology will lead to a 46 percent increase in the baseline and incremental warranty cost because of additional components covered under warranty. Also, the new technology was assumed to have a 20 percent higher failure rate in the early years. In ACT's analysis, the new technology was estimated to contribute to 24 percent of the overall incremental cost in California-only production.

CARB assumed that the additional costs for meeting the low NOx standards and durability will be accounted for in the R&D cost, not warranty cost, since the intent of warranty provisions is to protect the consumer from unforeseen production errors (e.g., a batch of improperly tempered steel, defective computer memory, bad solder joints, improper installation, etc.). CARB assumed that any potential increase in costs due to the lower NOx standard and new technology such as higher unit prices of emission-related components will be offset by gradual improvement in existing technology (e.g., early detection of failures by OBD), which was not accounted for in NREL/ACT Research/EMA's cost estimation. CARB staff believes that the comprehensive requirements of the Omnibus Regulation, including a more robust durability demonstration program, will ensure components will be designed to be more durable even under the lower NOx standard.

In addition, in response to EMA's comments on the draft report (Appendix G), CARB staff performed an additional sensitivity analysis evaluating the assumption of the warranty costs for new technology and estimated that if the warranty costs for new technology were included, it would increase the estimate of Omnibus Regulation costs by about 11 percent. The hypothetical increase is well within the bounds of the previous CARB Staff Report sensitivity analysis that incorporated the incremental warranty costs from the NREL report (CARB, 2020; see chapter IX.F). Therefore, staff concludes that even if higher warranty cost estimates due to new technologies were included, it would not have changed the staff proposal. More details of the additional analysis are shown in Appendix I.

2. Analysis of alternative scenarios

To better understand how each of the different assumptions made by CARB and EMA contributed to the warranty cost discrepancy, alternative scenarios were considered as summarized in Table IV.E.1. and Figure IV.E.1. For reference, scenario #1 is EMA's analysis based on aftermarket warranty pricing and #10 is CARB's Step 2 warranty incremental cost. The ratio of EMA's analysis to CARB's Step 2 is 11.9. The percentage change depends on the order of the scenarios and therefore should be considered as a rough guide only for evaluating the impact of each assumption. The waterfall chart shows that the assumptions regarding new technology and lower NOx standards (scenario #7, 8, and 9) have the biggest relative effect on the difference between CARB and EMA's estimates.

Table IV.E.1. Incremental costs of alternative scenarios applied to EMA's warranty cost calculation method

#	Scenarios	Incremental cost	Difference from previous scenario	Relative decrease from previous scenario
1	***EMA's analysis based on aftermarket warranty pricing***	$13,091	-	-
2	After using EMFAC-based incremental mileage without considering hour limit	$8,107	-$4,984	-38.1%
3	After using EMFAC-based incremental mileage considering hour limit (i.e., same incremental mileage as CARB)	$5,820	-$2,286	-28.2%
4	After increasing assumed markup of aftermarket warranty from 20% to 45%	$4,522	-$1,298	-22.3%
5	After assuming zero deductible for $300	$3,752	-$770	-17.0%
6	After assuming zero deductible	$3,624	-$128	-3.4%
7	After removing 20% elevated failure rate for new technology	$3,318	-$306	-8.4%
8	After removing 20% elevated failure rate at 0.02 g/bhp-hr NOx standard	$2,649	-$669	-20.2%
9	After removing additional warranty cost for new technology	$1,119	-$1,530	-57.8%
10	***CARB Step 2 Warranty (MY 2027 & 2031)***	$1,104	-$15	-1.3%

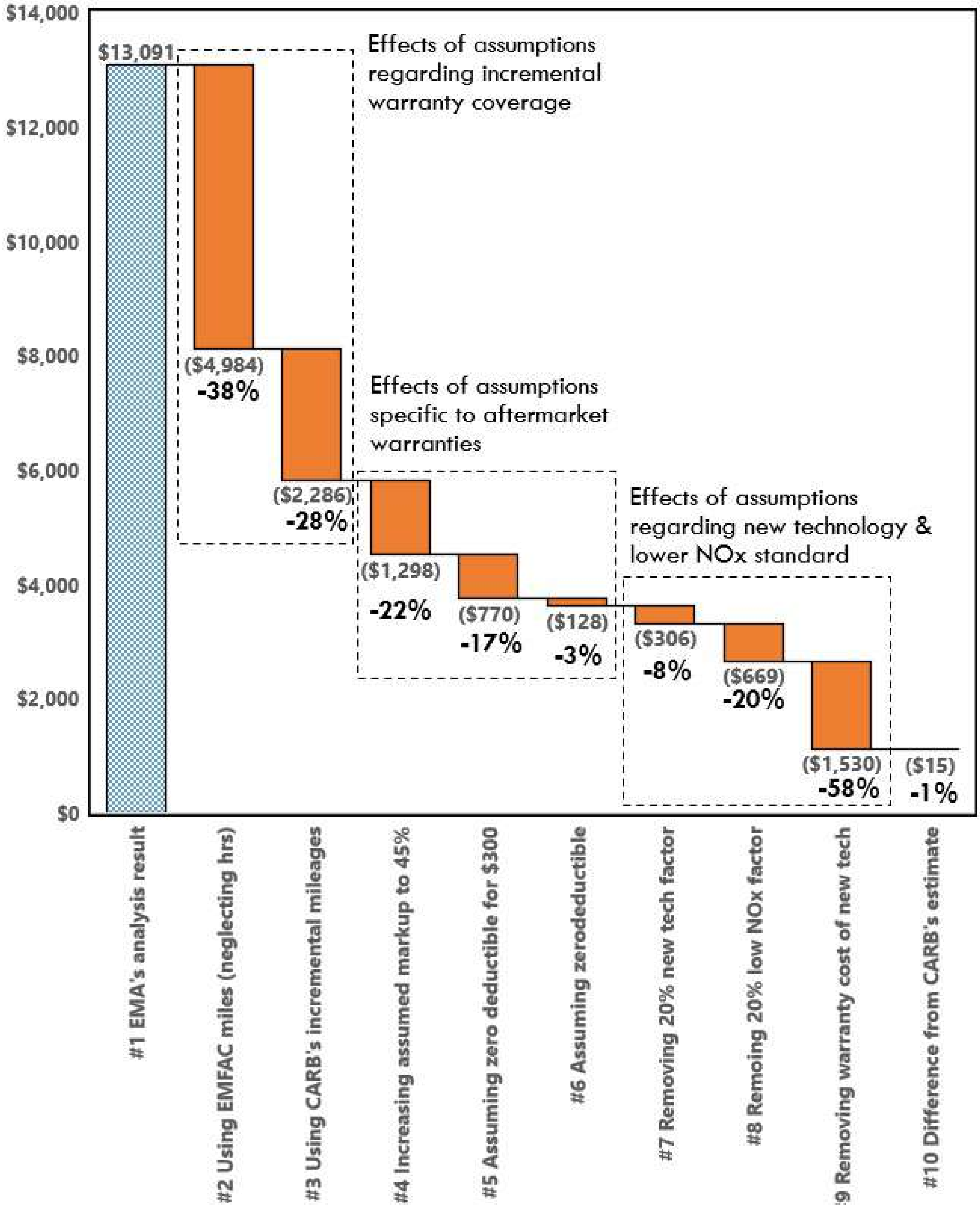


Figure IV.E.1. Effects of different assumptions on EMA's warranty cost estimates. The x-axis label corresponds to scenarios in Table IV.E.1.

Effects of assumptions regarding incremental warranty coverage (scenarios #2 and 3):

These calculations highlight the impact of accounting for the extended warranties purchased voluntarily. Scenario #2 implements CARB's calculation method of incremental miles covered under warranty using EMFAC simulations. The baseline scenario assumes that 40 percent of owners purchase 5 years / 500,000 miles warranty and 60 percent have Step 1 warranty (5 years / 350,000 miles). The average miles covered under warranty in this baseline is 288,692 miles (see section IV.A.3.b). The warranty end-point of scenario #2 assumes 10 years/600,000 miles neglecting a 30,000-hour limit consistent with EMA's assumption (section IV.D.2). To evaluate the effects of neglecting the hour limit, CARB staff estimated the average miles covered under warranty in MY 2031 without the hour limit in Table IV.E.2 shown below. The weighted average miles covered under warranty without the hour limit is 443,508 miles, in contrast to 399,843 miles that account for an hour limit (section IV.A.3.c). This means that in scenario #2 with a 10 year / 600,000 miles warranty, the average incremental miles covered under Step 2 warranty is 154,816 miles (i.e., 443,508 – 288,692 miles), as opposed to the apparent increase of 250,000 miles in warranty mileages (from 350,000 to 600,000 miles). Therefore, the warranty cost of scenario #1 ($13,091) is decreased to $13,091 * (154,816/250,000) = $8,107 in scenario #8.

In scenario #3 with 10 years / 600,000 miles / 30,000 hours warranty, the average incremental coverage decreases to 111,151 miles (i.e., 399,843 – 288,692 miles). As a result, the warranty cost is further decreased to $8,107 * (111,151/154,816) = $5,820.

Table IV.E.2. Hypothetical miles covered under Step 2 Warranty (MY 2031+) for EMFAC HHDV categories without 30,000-hour limitation. The shaded cells correspond to the factor determining the miles covered under warranty for each vehicle subcategory.

HHDV Warranty Mileage Estimates in MY 2031 and subsequent					
100% covered to 600,000 miles What if no hour limit?					
Vehicle Subcategory	Population %	10-year mileage	~~30,000 hours equivalent miles~~	Warranty Mileage	Miles Covered Under Warranty
Motor Coach	1.31%	611,967	~~1,232,271~~	600,000	600,000
T7 CAIRP	13.15%	800,000	~~1,232,271~~	600,000	600,000
T7 CAIRP Construction	1.19%	800,000	~~516,654~~	600,000	600,000
T7 Other port	0.70%	765,588	~~316,440~~	600,000	600,000
T7 POAK	2.57%	765,588	~~316,440~~	600,000	600,000
T7 POLA	7.74%	765,588	~~316,440~~	600,000	600,000
T7 Public	11.01%	88,776	~~604,272~~	600,000	88,776
T7 Single	11.79%	336,079	~~823,356~~	600,000	336,079
T7 Single Construction	8.29%	336,079	~~516,654~~	600,000	336,079
T7 SWCV	7.18%	178,500	~~328,544~~	600,000	178,500
T7 Tractor	21.75%	765,588	~~968,762~~	600,000	600,000
T7 Tractor Construction	5.54%	765,588	~~516,654~~	600,000	600,000
T7 Utility	0.27%	85,536	~~380,066~~	600,000	85,536
UBUS	7.50%	393,363	~~301,712~~	600,000	393,363
Weighted Average Mileage Covered for HHDV MY 2031 and subsequent: 443,508 miles					

Effects of assumptions specific to aftermarket warranties (scenarios #4, 5, 6):

The aftermarket warranty price provided to EMA contained an unknown amount of markup values in addition to labor and parts. EMA assumed that the markup value was 20 percent. In Step 1 Warranty, CARB staff considered up to 45 percent markup. To evaluate the sensitivity of the cost estimate on the unknown markup value, scenario #4 considered the impact of assuming 45 percent markup. Scenario #4 contains deductible costs for each repair. Scenario #5 assumes zero deductible for $300 based on the information provided by J.D. Power Valuation service (Appendix C). Scenario #6 assumes no deductible fee since CARB's method did not consider a deductible cost.

Effects of assumptions regarding new technology and lower NOx (scenarios #7, 8, 9):

As discussed in section IV.E.1.d, CARB staff disagrees with EMA and assumes that the engineering costs for meeting the lower NOx standard and durability requirements will be accounted for in the R&D costs, and gradual improvements in existing technology cancel out the potential increases in warranty costs of new technology. Therefore, CARB's warranty cost estimate does not include additional warranty costs associated with new technology and 0.02 g/bhp-hr NOx standard.

Also, the additional sensitivity analysis of the warranty costs for new technologies in Appendix I shows that even if higher warranty costs for the new technologies were incorporated, the Omnibus Regulation would continue to be cost-effective, and thus it would not have changed the staff proposal.

F. Conclusion of Goal #1: "Work collaboratively to better understand all of the assumptions made and all of the differences in the various warranty cost analysis methods"

During work group meetings, CARB and industry stakeholders engaged collaboratively to better understand all the assumptions made in CARB's method and multiple methods from NREL/ACT Research/EMA. In some cases, due to CBI, information was not available.

The previous section IV.E.2. identified the key assumptions that led to the discrepancies between CARB and EMA's analyses. The top three contributors to the discrepancies were found to be the following (Effects of all major factors are summarized in Figure IV.E.1):

- Assumed warranty costs for new technology (scenario #3);
- Use of EMFAC-based incremental mileage (including hour limit) (scenario #8,9); and
- Assumed elevated failure rates at 0.02 g/bhp-hr NOx standard (scenario #4).

Although CARB staff does not concur with EMA's methods, CARB staff agrees that the different viewpoints lead to different baseline assumptions that ultimately affect the respective warranty costing methodologies. CARB's method included optional longer warranties in the baseline to assess the impact of the rulemaking on the entire vehicle population. However, it is understandable that individual OEMs would consider the first point they encounter their customers, rather than the average vehicle population and overall cost shifts between operating and capital, which may have led to OEM's higher costs reported to NREL and ACT Research. The differences in major assumptions between CARB, NREL, ACT Research, and EMA are summarized in Table IV.E.3.

Table IV.E.3. Summary of Estimated Warranty Costs and Assumptions

	CARB Step 2 Warranty	NREL	ACT Research	EMA
Incremental warranty cost per HHDD engine[a]	$1,104	$23,061[b]	$7,227[c]	$13,091
Time periods	From MY2022 to MY2031	From MY2018 to MY2027[d]	From MY2019 to MY2031[d]	From MY2022 to MY2031
Warranty coverage baseline	500,000 mi/5 yr (40% of owners);[e] 350,000 mi/5 yr (60% of owners)[e]	Current warranty offered by the OEMs (not provided to CARB)[f]	250,000 mi 2 yr	350,000 mi 5 yr
Warranty coverage endpoints	600,000 mi 10 yr 30,000 hr	800,000 mi 12 yr	800,000 mi 12 yr[g]	600,000 mi 10 yr
Assumed NOx standards, g/bhp-hr FTP/RMC	0.020 @435,000 mi 0.040 @800,000 mi	0.02 @ 1 million mi	0.02 @ 1 million mi[g]	0.020 @435,000 mi 0.040 @800,000 mi

a: Caution must be taken when comparing the different costs because of the differences in the basic assumptions such as the baseline and warranty end-points.
b: Average-cost diesel technology package 12-13 L with CA-only volume
c: HHDD at 7% discount rate with CA-only volume
d: The baselines of NREL and ACT Research are before Step 1 warranty becomes effective (MY 2022), which overemphasizes the discrepancy between CARB and NREL/ACT Research.
e: Assumes no preference for regulatory vs. voluntary warranty
f: Each OEM chose their own 2018 baseline. It is unknown whether the baseline was CARB-warranty or OEM-provided base warranty because details are confidential.
g: CARB staff asked ACT research for clarification but did not receive a response. These numbers were based on work group members' suggestions.

In conclusion, major reasons why CARB's warranty costs are lower than industry's include the following:

- CARB's method includes the optional longer warranties in the baseline which reduces the cost impact of the rulemaking. CARB staff believes it is critical to include the optional longer warranties in the baseline to calculate the statewide cost impact of the rulemaking.

- CARB's method uses the EMFAC model to identify the factor that limits the warranty period (years, hours, miles) whereas NREL/ACT Research/EMA did not consider hours. CARB's method is the most transparent in terms of how years, hours, and miles are considered in determining the warranty coverages.

- CARB's method assumes the repair costs per miles covered under warranty stay the same after introduction of lower NOx standards and new technologies because a future technology package must be designed to be durable through its useful life, and the R&D cost is counted as useful life cost. CARB staff believes this assumption is consistent with warranty's intent to cover only the defects, not failures of components that are not designed to be durable.

V. Goal #2: Gather available data for heavy-duty vehicles to quantify the residual warranty value to the second and subsequent owners.

As the regulatory warranty periods are lengthened through Step 1 and 2, it is likely that more vehicles produced under these newer warranty requirements will be later re-sold in the secondary market as used vehicles with a portion of the lengthened warranty period coverage remaining (i.e., residual warranties). To better understand the secondary market value of such residual warranties, an on-line survey was collected from heavy-duty vehicle owner/operators and dealers. The survey results showed that the residual emission warranties add significant resale values to used vehicles.

A. Methods

CARB staff drafted a survey, which was then provided to all work group members to review. Comments were provided by EMA, Cummins, and ATA. CARB staff then did a survey pre-test of several fleets to get preliminary feedback. Where questions were ambiguous, CARB revised the survey. A set of survey questions were finalized (Appendix D) and implemented via a SurveyMonkey® questionnaire. CARB staff sent out emails to 59,424 owner/operators and 41 dealers. CARB staff obtained the email addresses of owner/operators from CARB's Truck and Bus Regulation Reporting (TRUCRS) database and dealers. 1,295 raw responses were acquired. After screening responses that spent less than 1 minute and answered only one question, the total screened responses were 699. Five dealerships responded. While there is higher uncertainty in the dealership estimated residual warranty values than from the owner/operator responses, these dealer responses provide an important view into sellers' understanding and attitudes regarding residual warranty value.

B. Survey Results

The following figures characterize the owner/operators who responded to the survey based on their fleet size (Figure V.B.1), vehicle weight class (Figure V.B.2), fuel type (Figure V.B.3), fleet service type (Figure V.B.4), vehicle age (Figure V.B.5), how emission control-related maintenance is handled (Figure V.B.6), how emission-related warranty repairs are handled (Figure V.B.7), and whether they purchase vehicles new or used (Figure V.B.8). The x-axes of the following plots generally represent the percentage of survey responses. For example, responses from single vehicle owner/operators and 50+ vehicle fleet weigh equally.

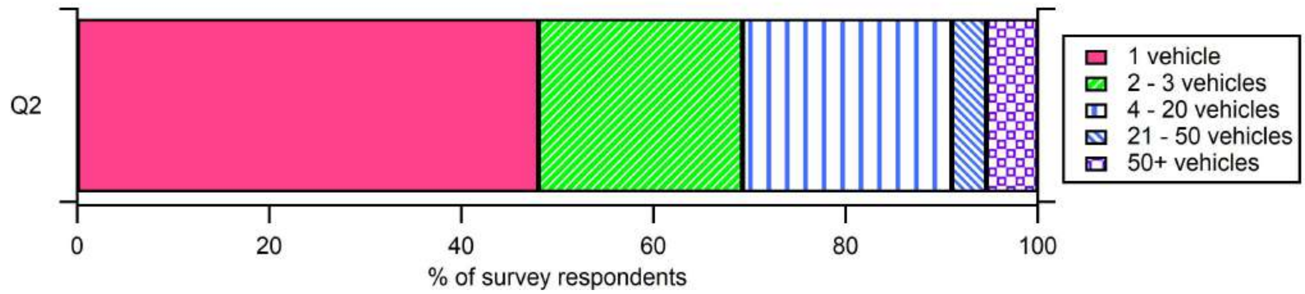


Figure V.B.1. How many heavy-duty vehicles (gross vehicle weight rating > 14,000 pounds) are in your fleet? (Question #2)

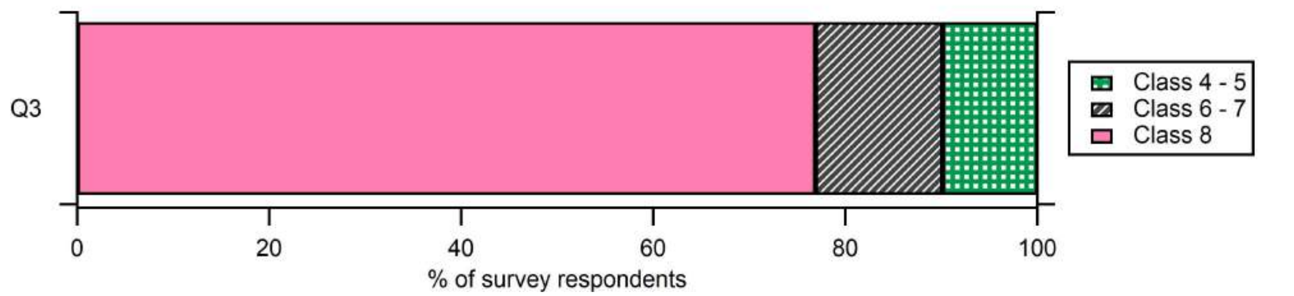


Figure V.B.2. What weight class are your vehicles (i.e., what gross vehicle weight rating (GVWR))? (e.g., do you have 100 percent class 8 or a mixture of classes, indicate the percent below with the total adding to 100) (Question #3)

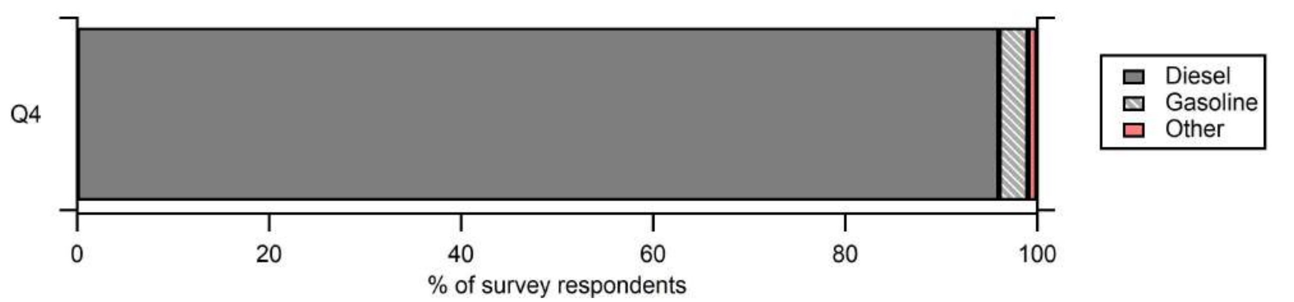


Figure V.B.3. What truck fuel types are used in your fleet? Indicate the percent below with the total adding to 100. (Question #4)

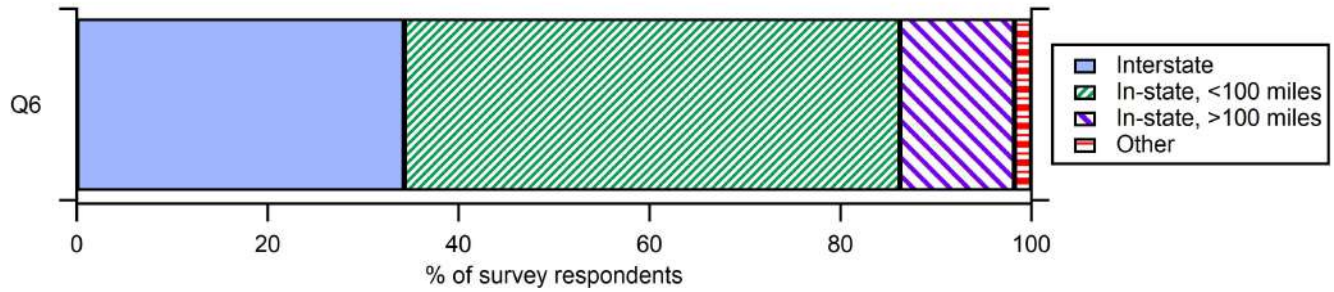


Figure V.B.4. List the approximate percentage of your fleet by service type(s). The percent below should add to 100. (Question #6)

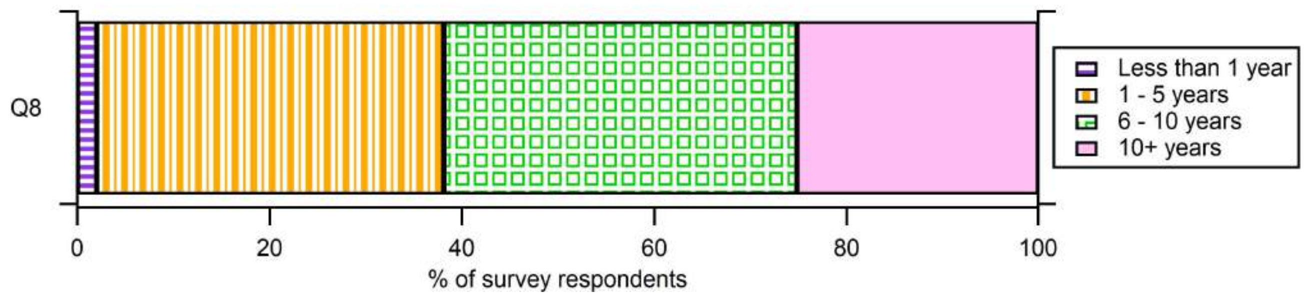


Figure V.B.5. What is the average age of heavy-duty vehicles in your fleet? (Question #8)

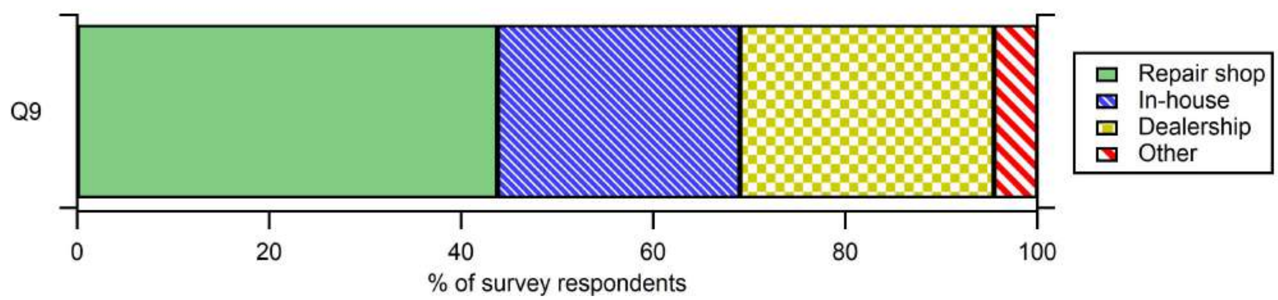


Figure V.B.6. How do you typically handle emission control-related (EGR valves, turbochargers, NOx sensors, SCRs, DPFs) maintenance (e.g., adjustments, cleanings, replacements)? Choose as many as applicable. (Question 9)

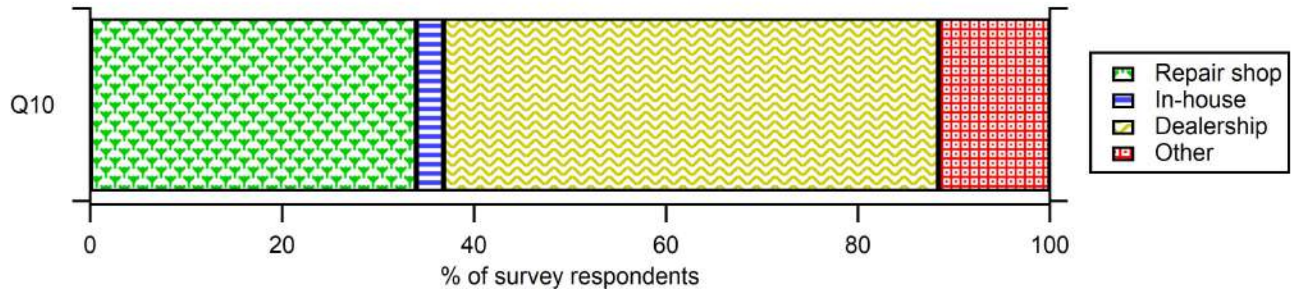


Figure V.B.7. How do you handle emission-related warranty repairs? (Question 10)

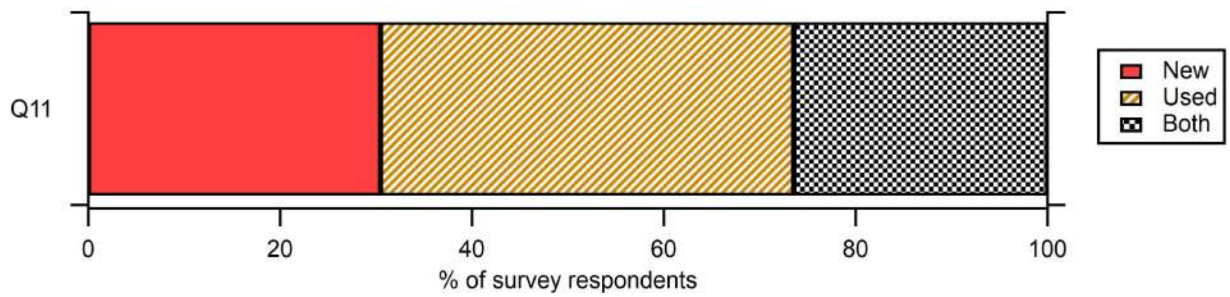


Figure V.B.8. Do you typically buy your vehicles new or used? (Question 11)

To better understand the value of residual warranties from sellers' and buyers' perspectives, the following figures compare responses from those who typically purchase vehicles new, used, or both (new and used). Figure V.B.9 shows that most used vehicle owners are either unsure about the warranty or do not have warranties ("Not Applicable").

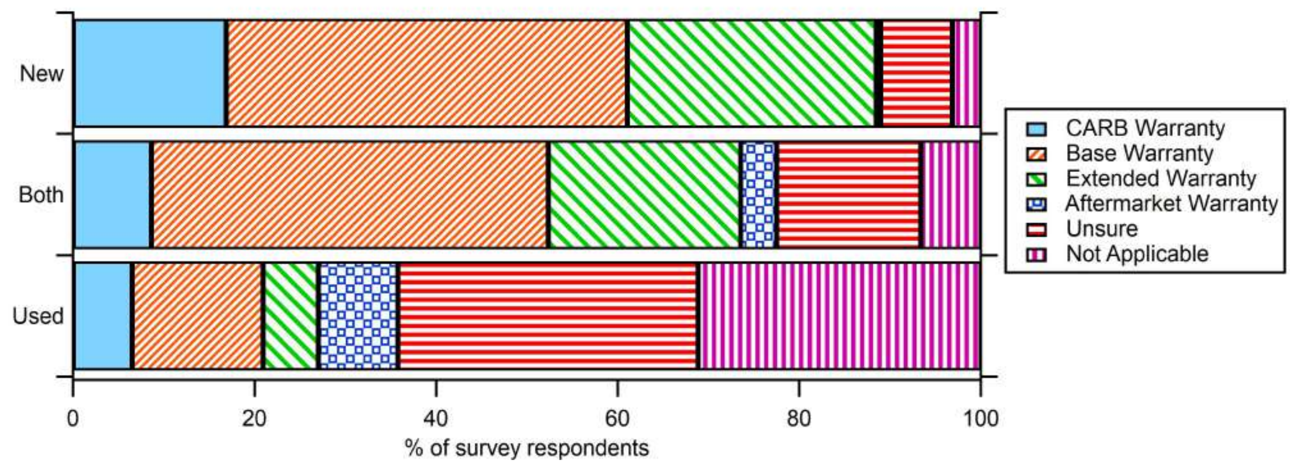


Figure V.B.9. What is your typical warranty type? (Question #12, #19, and #31)

Figure V.B.10 shows that for most owner/operators, cost of repairs and dependability determine how long they keep their vehicles. A small number of respondents indicated that they have set numbers of years/miles for retiring the vehicles from their fleet. Approximately half of respondents expect to hold on to their vehicles longer because of CARB's longer emission warranty periods (see Figure V.B.11). More than half of respondents sell their vehicles through private sales (see Figure V.B.12).

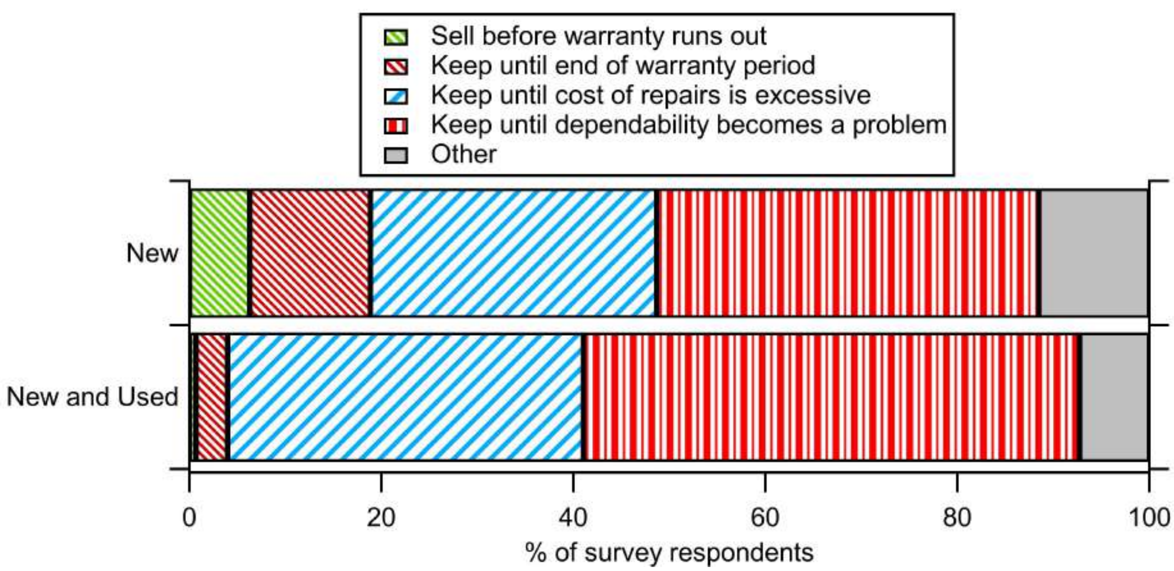


Figure V.B.10. How long do you typically keep your vehicles? (Question #13 and #32)

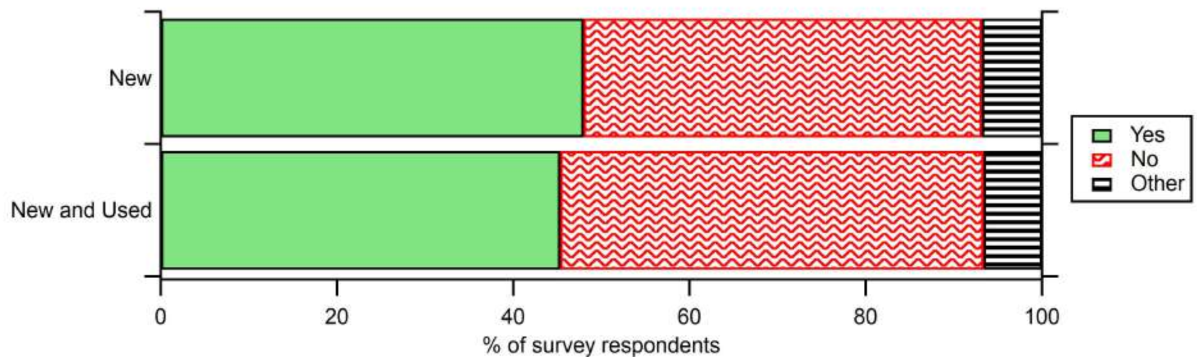


Figure V.B.11. Do you expect this practice will change because of CARB's longer emissions warranty periods? In other words, will a longer emissions-related component warranty (assuming all other warranties remain the same) cause you to hold on to the vehicles longer? (Question #15 and #34)

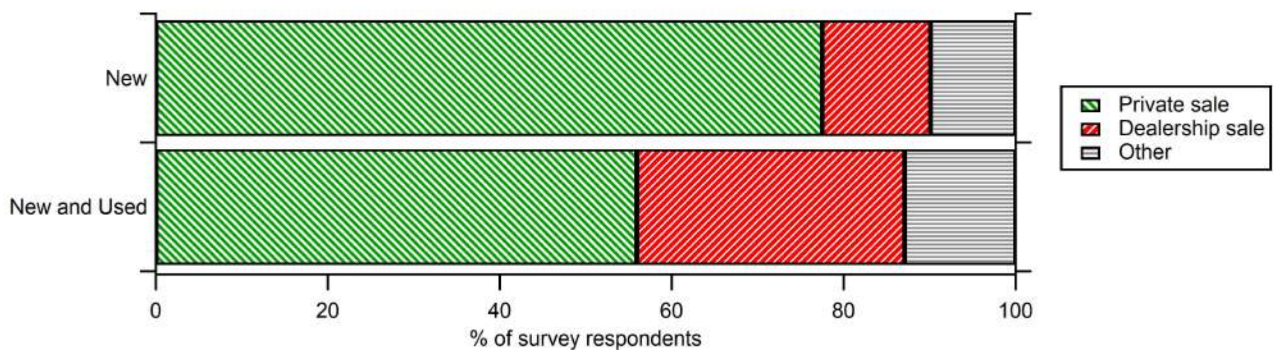


Figure V.B.12. Where do you sell your vehicles? (Question #16 and #35)

To obtain the estimated values of the residual warranties from those who typically purchase vehicles new, used, or both (new and used), as well as from dealers, a similar set of questions was created with slightly different wording. For example, Question #17 is for new vehicle purchasers:

> ***Question #17 for new vehicle purchasers:***
> Hypothetically speaking, if you are selling a class 8 vehicle with <u>2 years/200,000 miles</u> of remaining emission-related component warranty that covers everything related to the malfunction indicator light (MIL), how much more would you expect to get for a vehicle with the remaining emission warranty compared to one without it (the same production year, mileage, planned future use)? Please consider the vehicle class and fuel type that best represents your fleet.

a. \$0 - 999
b. \$1,000 – 1,999
c. \$2,000 – 2,999
d. \$3,000 – 4,999
e. More than \$5,000 (please specify)

For used vehicle purchasers, the question was rephrased to ask how much of a higher price they would be willing to pay using the same multiple choices. The survey did not evaluate the impact of different year-to-mile ratios (e.g., 6 months/200,000 miles, etc.) because it would have added complexity to the survey process. When analyzing the results, the mid-point values (e.g., \$2,500 for \$2,000 – 2,999) were taken and the 95 percent confidence intervals (CI) were calculated as

$$CI = \bar{x} \pm t \times \frac{s}{\sqrt{n}}, \qquad \text{(Equation V.5)}$$

Where $\bar{x}$ is the mean, *t* is the corresponding *t*-value (two-tailed, significance level 0.05), *s* is the standard deviation, and *n* is the sample number.

Figure V.B.13 summarizes the estimated values of residual warranties. The responses were grouped into new vehicle purchasers (those who sell used vehicles), used vehicle purchasers (those who buy used vehicles), new and used vehicle purchasers (as sellers), and new and used vehicle purchasers (as buyers). Responses from five dealers are also included for completeness, but the small sample number leads to the large error bars. The results in Figure V.B.13 indicate that the residual warranties have significant values, approximately 1 cent/mile, generally within a factor of two. Also, it was found that the sellers tend to value residual warranty more than buyers do.

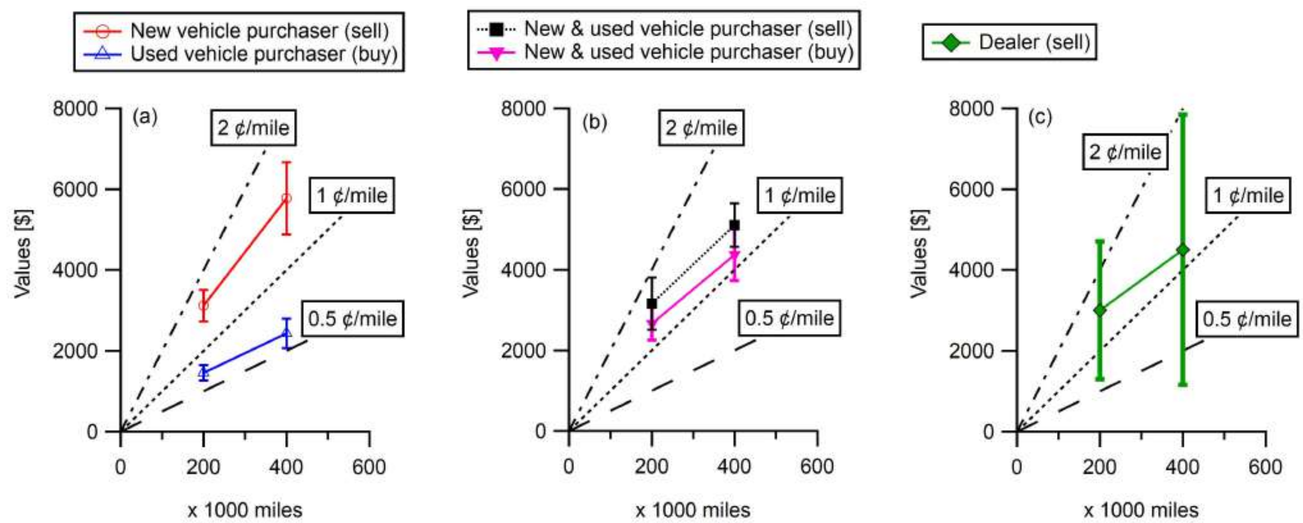


Figure V.B.13. The expected values of residual warranties as a function of remaining warranty mileages: (a) New vehicle purchasers and used vehicle purchasers, (b) New and used vehicle purchasers as sellers and as buyers, and (c) Dealers (Question #17, #18, #21, #22, #29, #30, #36, and #37).

C. Conclusion of Goal #2

The survey results collected from 694 fleets and owner/operators indicate that residual warranties have significant value, approximately 1 cent/mile. Those who sell used vehicles tend to put higher price values on the residual warranties than those who buy the used vehicles. Approximately half of the respondents expect to hold on to vehicles longer as CARB extends warranty periods. These results suggest that higher initial vehicle purchase prices are likely to be passed on to the subsequent vehicle owners, which potentially reduces the cost impact that the Omnibus Regulation warranty amendments may have on first owners.

VI. Goal #3: Gather available data on usage patterns and duty cycles from the second and subsequent owners of vehicles used in a variety of applications to assess wear characteristics.

MECA and MEMA represent the suppliers of emission control components used by OEMs, and specifically requested that Goal #3 be included in the warranty study. MECA and MEMA representatives requested that CARB staff identify and provide references to previous studies relevant to Goal #3. The following references were provided to MECA and MEMA:

- "Collection of Activity Data from On-Road Heavy-Duty Diesel Vehicles" by the Bourns College of Engineering, Center for Environmental Research & Technology (CE-CERT) (CE-CERT, 2017)
- CARB EMFAC Fleet Database: *https://arb.ca.gov/emfac/fleet-db*
- "Updates to Heavy-Duty Emission Deterioration in EMFAC" by Eastern Research Group, Inc (ERG) (ERG, 2020)
- "Heavy-Duty Vehicle Accrual Rates" (ERG, 2019)

MECA and MEMA members found the references helpful in longer life design of aftertreatment. Engine component suppliers indicated that further studies are needed to understand wear characteristics of used (not failed parts) parts such as injectors, turbos, and EGR coolers. Catalyst suppliers indicated that in future studies for EMFAC model updates, it would be useful to collect the following:

- Mileages of the vehicles studied;
- Location of the SCR temperatures (inlet or outlet);
- Season of study, summer versus winter; and
- Oil and fuel usage.

MECA and MEMA members wished to have information on what failed, when did it fail, what was the duty cycle during its life, mileage at the time of failure, and OBD information at the time of failure and would like to explore obtaining this data via CARB warranty reporting. They also wanted to have the parts for post-mortem analysis.

Staff concluded that there is variation in the post-mortem failure data and analysis that their members receive. While some members are privy to this information, smaller suppliers are not. Although additional requirements for submitting failure-related information may benefit some part suppliers, CARB is currently not storing this information. In addition, it would take up to five years for data to become available, and therefore it is unlikely that part suppliers could quickly and comprehensively obtain relevant information. To provide more immediate information to part suppliers, CARB staff offered to analyze and provide common failure modes reported to CARB through FIRs. The result is summarized in section VIII (Goal #5).

VII. Goal #4: Make a plan for gathering and sharing data between OEMs and suppliers as new technologies to meet MY 2024 and MY 2027 standards are rolled out.

To achieve Goal #4, CARB staff drafted a survey that covered a broad range of issues ranging from the information exchange between OEMs and suppliers that occurs during the development process in designing specifications for components including questions on how information is shared with regards to warranty claims and who pays for the cost of replaced components. However, upon discussion with MECA representatives, CARB staff was advised not to conduct the survey. Developing specifications for components that last the full useful life and agreeing to responsibility with regards to warranty is tied to individual business agreements between suppliers and their customers that depends on many different factors. Every OEM handles it differently so a supplier that provides components to different OEMs may have very different arrangements based on their business relationship. Each OEM will likely have different warranty arrangements with each supplier based on the value of the component that is being supplied, the relative size of the business and other factors as well. Because of the diversity of these business arrangements, MECA representatives thought it would be difficult to make a conclusion from a potential OEM-supplier survey. As a result, a survey was not executed. Therefore, CARB staff concluded that Goal #4 was not feasible to achieve as part of this study. To assist part suppliers in improving the durability of their parts, CARB staff offered to summarize common failure modes as discussed in section VIII (Goal #5). As part of this study, CARB staff met individually with OEMs and confirmed that some of the OEMs are in discussion with suppliers regarding MY 2022 warranty requirements. CARB will continue to monitor the process as the industry prepares to meet MY 2024 and MY 2027 requirements.

VIII. Goal #5: Facilitate discussions between OEMs and emission control component suppliers beyond the current 100,000-mile warranty period.

As noted above regarding Goal #4, MECA representatives advised CARB not to conduct the OEM-supplier survey to achieve Goal #5. Without meaningful data, discussion was very limited.

To provide alternative information useful to suppliers however, CARB staff analyzed the top 3 failure modes for critical emission control components based on FIRs for the 2013-2019 MYs. Light Heavy-Duty Diesel (LHDD), Medium Heavy-Duty Diesel (MHDD), and HHDD engine families were included in the study. The failures of these components occurred within the 5 year/100,000-mile emissions warranty, base engine warranty, or paid extended warranty periods. The top three failure modes were not necessarily ranked in order of most common occurrence. They were based on how frequently engine families experienced a failure mode for a particular emissions control component so that the rankings would not be skewed by engine families with large populations. Conducting an analysis in this manner better represents how parts are failing in the field across many engine families as the results are not weighted by the size of the population of each engine family. For these reasons, this study can be considered more of an engine family-based survey than a quantitative analysis of the highest-ranking failure mode for a particular emissions control component.

It is important to note that manufacturers have different designs for components. Even if manufacturers used the same design for a component from the same supplier, calibrations may be different, and they may be used for different applications which would impact how they could potentially fail. There may even be variability in components used for engines in the same engine family if an improved version of a component is introduced as a replacement part and not equipped on all engines.

Table VIII.1 Common failure modes for critical emission control components determined by examining FIRs for the 2013-2019 MYs

Components	Failure modes
Injector	1. Physical damage due to corrosion 2. Wearing of needle control valve 3. Electrical Issue
SCR	1. Catalyst is deactivated in the presence of water during low to high temperature cycling 2. Software Issue
DEF Pump	1. Particle contamination damaging pumping membrane 2. Software Issue
DEF Dosing Valve	1. Software Issue 2. Clogged Injector 3. Leaking Doser
DPF	1. Excessive soot load leading to cracking 2. Filter Clogged 3. Software Issue
Aftertreatment Hydrocarbon Injector	1. Clogged Injector
EGR Valve	1. Valve sticking due to contamination 2. Software issue
EGR Cooler	1. Cleaning is necessary 2. Thermal fatigue 3. Assembly issues
Fuel Pump	1. Control valve sticking 2. Contaminated fuel
Computer	1. OBD/Software issue 2. Hardware replacement
Turbocharger	1. Cycle fatigue 2. Coolant leak 3. Sector shaft/gear binding
NOx Sensor	1. Moisture contacting sensor element 2. Cracking due to thermal shock 3. Software Issue
PM Sensor	1. Clogged sensor tip 2. Software Issue
Ammonia Sensor	1. Sensor circuit error 2. Rusted/Corroded
Urea Quality Sensor	1. Liquid Ingress 2. Communication Error

IX. Goal #6: Review the results and the suggested next steps from the study.

This chapter summarizes the findings related to each of the first five goals.

Goal #1: Work collaboratively to better understand all the assumptions made and all of the differences in the various warranty cost analysis methods.

Over a nine-month period, the working group met 16 times to work collaboratively and better understand the assumptions in the warranty cost analysis methods. The outcomes of Goal #1 clarified the reasons for the discrepancies between CARB and NREL/ACT Research/EMA's warranty costs. Two major factors are identified:

1) CARB and EMA have different interpretations of the meaning of warranty costs.
    - CARB assumes that a properly engineered technology package should be durable through its useful life. CARB assumes warranty costs cover unforeseen failures of properly engineered parts.
    - EMA expects more failures as new technologies are introduced and NOx standards tightened. It is possible that some manufacturers made similar assumptions when they responded to NREL and ACT Research's surveys although the assumptions made by each manufacturer are confidential.
2) CARB and NREL/ACT Research/EMA have different baselines and incremental warranty coverages
    - CARB's warranty baseline is higher than NREL/ACT Research/EMA because CARB accounts for optional 5 years / 500,000 miles warranties that 40 percent of the vehicle population are expected to have for MY 2022.
    - CARB's warranty endpoint is lower than NREL/ACT Research/EMA because CARB uses the EMFAC model to account for the limiting factors such as years, hours, or miles and the vehicle population.

Because of these fundamental differences in the interpretation of warranty coverages and costs, direct comparison of the warranty costs resulted in a large discrepancy by an order of magnitude.

> ***Suggested Next Step:*** Although CARB and the work group members were not able to agree on which methods should be used generally to estimate warranty cost, it was suggested that future warranty cost estimates clarify key assumptions on the definition of warranty cost (e.g., distinction between useful life cost vs. warranty cost) and how incremental coverage is calculated (e.g., how years/hours/miles limits are treated, etc.) because these assumptions are major sources of the apparent discrepancies.

Goal #2: Gather available data on heavy-duty vehicles to quantify the residual warranty value to the second and subsequent owners.

CARB surveyed and collected responses from 694 fleets and owner/operators as discussed in section V (Goal #2). Results indicate that fleets and owner/operators expect approximately 1 cent/mile (within a factor of two) value in residual warranties. For example, when a used vehicle with 2 years/200,000 miles of remaining emission-related warranty is sold, the owner expects to receive approximately $2,000 as a result of this residual warranty. Also, survey results indicated that approximately half of the fleets/owner/operators expected to hold on to their vehicles longer as CARB extends the warranty periods. These results suggest that higher initial purchase prices are likely to be distributed over longer time periods or passed on to the subsequent owners to some extent, which lessens the impact of the potential price increase.

Suggested Next Step: As warranty periods become longer and more used vehicles are sold with residual warranties in the future, it may be helpful to collect more sales data on the value of residual warranties of actual vehicles in the secondary market.

Goal #3: Gather available data on usage patterns and duty cycles from the second and subsequent owners of vehicles used in a variety of applications to assess wear characteristics.

CARB staff provided MECA and MEMA members useful references for longer-life design of emission-related components.

Suggested Next Step: MECA and MEMA representatives suggested CARB to consider future long-term studies that collect information on:

- Mileages of the vehicles studied;
- Location of the SCR temperatures (inlet or outlet);
- Season of study, summer versus winter; and
- Oil and fuel usage.

Goal #4: Make a plan for gathering and sharing data between OEMs and suppliers as new technologies to meet MY 2024 and MY 2027 standards are rolled out.

In discussions with supplier representatives, CARB staff was advised that OEM-supplier business relationships vary widely and that particular sensitivities exist when it comes to information sharing. Therefore, the group decided that there was not a clear path for CARB to intervene between OEMs and suppliers to facilitate information sharing more than what exists today.

Suggested Next Step: None

Goal #5: Facilitate discussions between OEMs and suppliers beyond the current 100,000-mile warranty period.

As in Goal #4, the group decided that there was not a clear path for CARB to intervene between OEMs and suppliers to facilitate information sharing more than what exists today. To provide alternative useful information to suppliers, CARB staff analyzed available FIRs to determine the top two to three failure modes of critical emission control components. Supplier representatives noted that data generated in Goal 3 is necessary to better understand the failure mechanisms and rates that lead to the top failure modes CARB reports from its summary of warranty data.

Suggested Next Step: None

X. References

(CARB, 2018) Staff Report: Initial Statement of Reasons for Proposed Rulemaking, "Public Hearing to Consider Proposed Amendments to California Emission Control System Warranty Regulations and Maintenance Provisions for 2022 and Subsequent Model Year on-Road Heavy-Duty Diesel Vehicles and Heavy-Duty Engines with Gross Vehicle Weight Ratings Greater Than 14,000 Pounds and Heavy-Duty Diesel Engines in Such Vehicles," (Step 1 Warranty), California Air Resources Board May 8, 2018. https://ww3.arb.ca.gov/regact/2018/hdwarranty18/isor.pdf?_ga=2.14983222.1608313504.1619533513-1362703053.1594203696

(CARB, 2019) California Air Resources Board Staff Current Assessment of the Technical Feasibility of Lower Nox Standards and Associated Test Procedures for 2022 and Subsequent Model Year Medium-Duty and Heavy-Duty Diesel Engines, April 18, 2019, https://ww2.arb.ca.gov/sites/default/files/classic//msprog/hdlownox/white_paper_04182019a.pdf

(CARB, 2020) Staff Report: Initial Statement of Reasons for Proposed Rulemaking, "Public Hearing to Consider the Proposed Heavy-Duty Engine and Vehicle Omnibus Regulation and Associated Amendments: Proposed Amendments to the Exhaust Emissions Standards and Test Procedures for 2024 and Subsequent Model Year Heavy-Duty Engines and Vehicles, Heavy-Duty on-Board Diagnostic System Requirements, Heavy-Duty in-Use Testing Program, Emissions Warranty Period and Useful Life Requirements, Emissions Warranty Information and Reporting Requirements, and Corrective Action Procedures, in-Use Emissions Data Reporting Requirements, and Phase 2 Heavy-Duty Greenhouse Gas Regulations, and Powertrain Test Procedures," (Heavy-Duty Omnibus), California Air Resources Board, June 23, 2020. https://ww3.arb.ca.gov/regact/2020/hdomnibuslownox/isor.pdf

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(EMA, 2020) Comments of the Truck and Engine Manufacturers Association, August 13, 2020. https://www.arb.ca.gov/lists/com-attach/8-hdomnibus2020-1jACGvmafqDgElXk.pdf

(ERG, 2019) Heavy-Duty Vehicle Accrual Rates, Carb Final Report, Erg No. 3982. 01. 001, June 14, 2019, https://ww2.arb.ca.gov/sites/default/files/2021-01/erg_finalreport_hdv_accruals_20190614.pdf

(ERG, 2020) Updates to Heavy-Duty Emission Deterioration in Emfac, Carb Agreement No. 17aqp006, Report Version 3, July 21, 2020, https://ww2.arb.ca.gov/sites/default/files/2021-02/carb_hd%20emfac_det_rates_v3_20200721.pdf

(ISR, 2017) Survey and Analysis of Heavy-Duty Vehicle Warranties in California | 15msc009, Institute for Social Research, California State University, Sacramento, December 2017. https://ww3.arb.ca.gov/regact/2018/hdwarranty18/apph.pdf

(NREL, 2020) On-Road Heavy-Duty Low-Nox Technology Cost Study, National Renewable Energy Laboratory, May 2020. https://www.nrel.gov/docs/fy20osti/76571.pdf

(Sharp, C., 2021) Further Development and Validation of Technologies to Lower Oxides of Nitrogen Emissions from Heavy-Duty Vehicles. Low Nox Demonstration Program - Stage 3, https://www.arb.ca.gov/lists/com-attach/79-hdomnibus2020-Uj4AaQB2Aj8FbAhw.pdf

XI. Appendix

A. Excerpt of the August 27, 2020 board hearing transcript regarding the warranty cost study

The entire transcript is available at https://ww3.arb.ca.gov/board/mt/2020/mt082720.pdf

<Mobile Source Control Division (MSCD) Assistant Division Chief Carter>

From page 294 line 24 to page 295 line 25:

> MSCD ASSISTANT DIVISION CHIEF CARTER: Okay. Well, thank you very much. I appreciate that. So I think one of the other issues that was brought up by industry, Cummins in particular, and I think MECA and others, was the warranty implications after 2027, and what the costs associated with those would be.
>
> We're pretty confident in our cost estimates and what we believe is doable in our estimates, that kind of a thing. But on the other hand, we also recognize just the unknown from the industry and from the manufacturers. And So they suggested -- a couple people suggested that perhaps we engage in some sort of a cost study -- a deeper dive cost study. And this would give the information -- more information for the industry to assess what those costs would be. It would also help the industry plan for the warranty costs and warranty associated with it, that kind of a thing.
>
> And from the staff's perspective, we're perfectly open to some sort of a joint study, cooperative study in the next year or so, so we can do a deeper dive. We will learn from it and so will the industry. So just from the staff's perspective, we're certainly fine with that.
>
> We're not -- just to make it clear, there was also a suggestion of delaying the warranty requirements. We're not in favor of that at all. But again, we are certainly in favor of doing some sort of a cost study, joint study with them.

<Vice Chair Berg>:

From page 311 line 14 to page 312 line 4:

> I am concerned with the time frame for 2027 with new technology and a big bump up in warranty. And so I'm supportive of the industry and staff suggestion to undergo a cost study, which would include understanding that interaction between parts manufacturers and the people that put all the parts together to create systems. These are all parts of a warranty issue. But I really want to know that both industry and staff are going to go into that study with an open mind to the outcome. And if it shows that we were -- had it right, then industry is going to get behind it. But staff if it shows that we missed the mark that we're going to come back and do something about it.

> So I think it's only wise to go into such a study if all parties are truly committed to going through that process and honoring the outcome.

<Chair Nichols>

From page 338 line 23 to line 25:

> Sandy raised the warranty study. I think that sounds like that's in the works or will be in the works when this rule passes and we'll accomplish what we needed to accomplish.

B. Excerpt of the email from EMA regarding the warranty cost data from OEMs for Step 1 warranty

Sent: Friday, June 18, 2021 12:31 PM
Subject: Aggregated Average Costs of CARB's First-Step Extended Warranties

As a follow-up to our last call, and based on the available data EMA has gathered, aggregated, and averaged, the cost of CARB's first-step extended warranty will be approximately $3,750 for larger 15L engines, and approximately $2,500 for 11-13 L engines. The cost increase for MHD engines will be approximately $1,400. Please note that these average cost increases do not include OEM mark-ups or FET impacts.

C. Warranty values estimated by J.D. Power Valuation Services

WARRANTY VALUES

Level 1	**48 mo./400,000 miles**	**$6400**

Full driveline coverage (engine, transmission, rear axles), including internal and external engine components and accessories.

Level 2	**36 mo./1,000,000 miles**	**$5500**

Full driveline coverage (engine, transmission, rear axles), including internal and external engine components and accessories.

Level 3	**36 mo./300,000 miles**	**$5000**

Full driveline coverage (engine, transmission, rear axles), including internal and external engine components and accessories.

Level 4	**24 mo./200,000-250,000 miles**	**$3750**

Full driveline coverage (engine, transmission, rear axles), including internal and external engine components and accessories.

Level 5	**24 mo./200,000-250,000 miles**	**$3400**

Coverage of internal and external engine components and accessories and transmission.

Level 6	**24 mo./200,000-250,000 miles**	**$2850**

Coverage of internal and external engine components and accessories.

Level 7	**12 mo./100,000-125,000 miles**	**$2500**

Full driveline coverage (engine, transmission, rear axles), including internal and external engine components and accessories.

Level 8	**12 mo./100,000-125,000 miles**	**$2100**

Coverage of internal and external engine components and accessories and transmission.

Level 9	**12 mo./100,000-125,000 miles**	**$1750**

Coverage of internal and external engine components and accessories.

Level 10	**6 mo./50,000 miles**	**$1250**

Full driveline coverage (engine, transmission, rear axles), including internal and external engine components and accessories.

Level 11	**6 mo./50,000 miles**	**$1000**

Coverage of internal and external engine components and accessories and transmission.

Level 12	**6 mo./50,000 miles**	**$ 750**

Coverage of internal and external engine components and accessories.

For all warranty levels:

Add	$0 Deductible	**$ 300**
Add	DPF Coverage	**$ 750**
Add	EGR Valve Coverage	**$ 500**
Add	Free Towing Included	**$ 500**
Ded	Without Electronic Engine Controller Coverage	**$ 750**
Ded	Without Turbocharger Coverage	**$ 1000**

For warranty transfers, values may be pro-rated proportionally to the time/mileage remaining in the warranty.

It is at the user's discretion to arrive at a value for other packages not mentioned on this page. Be sure to obtain all available documentation to assist in the appraisal.

D. Residual warranty survey questions

Business category:

1) Please choose your business

- Fleet owner or Owner operator
- Vehicle Dealership

Fleet and Owner/Operators Questions:

2) How many heavy-duty vehicles (gross vehicle weight rating > 14,000 pounds) are in your fleet?

- 1
- 2-3
- 4-20
- 21-50
- 50+

3) What weight class are your vehicles (i.e., what gross vehicle weight rating (GVWR))? (e.g., do you have 100% class 8 or a mixture of classes, indicate the percent below with the total adding to 100)

- GVWR greater than 33,000 lbs (Class 8): ___________________
- GVWR 19,501 to 33,000 lbs (Class 6 and 7):___________________
- GVWR 14,000 to 19,500 lbs (Class 4 and 5):___________________

4) What truck fuel types are used in your fleet? Indicate the percent below with the total adding to 100.

- Diesel: __________________
- Natural Gas (CNG or LNG): __________________
- Gasoline: __________________
- Other: __________________

5) If "Other", please identify.

6) List the approximate percentage of your fleet by service type(s)? The percent below should add to 100.

- In-state operation & delivery within 100-mile radius from the fleet base
- In-state operation & delivery greater than 100-mile radius from the fleet base
- Interstate operation
- Other (please describe) ____

7) If "Other", please identify.

8) What is the average age of heavy-duty vehicles in your fleet?

- Less than 1 year
- 1-5 years
- 6-10 years
- More than 10 years

9) How do you typically handle emission control-related (EGR valves, turbochargers, NOx sensors, SCRs, DPFs) maintenance (e.g., adjustments, cleanings, replacements)? Choose as many as applicable.

- Do maintenance in-house
- Do maintenance at a repair shop
- Do maintenance at the dealership
- Other (please describe) ________

10) How do you handle emission-related warranty repairs?

- Take vehicles to a repair shop
- Take vehicles to the dealer
- Fleet authorized to do in-house warranty work
- Other (please describe) _______

11) Do you typically buy your vehicles new or used?

- Both (→ Go to question #12-20)
- New (→ Go to question #12-17)
- Used (→ Go to question #18-20)

For new vehicle purchasers:

12) What is your typical warranty type?

- CARB warranty (5 years / 100,000 miles)
- Base warranty provided by the manufacturer/dealer (Example: 2 years / 250,000 miles)
- Extended warranty provided by the manufacturer/dealer
- Aftermarket warranty provided by a third party
- Unsure
- Not applicable (please specify)

13) How long do you typically keep your vehicles?

- Sell before warranty runs out
- Keep until end of warranty period
- Keep until cost of repairs is excessive
- Keep until dependability becomes a problem
- Other (please specify)

14) If you answered, "Sell before warranty runs out", do you typically cash in the remaining warranty (i.e., get a pro-rated refund for the amount of the unused warranty) on the vehicles prior to selling them back to the dealer?

- Yes
- No
- Other (please describe)

15) Do you expect this practice will change because of CARB's longer emissions warranty periods? In other words, will a longer emissions-related component warranty (assuming all other warranties remain the same) cause you to hold on to the vehicles longer?

- Yes
- No
- Other (please specify)

16) Where do you sell your vehicles?

- Private sale e.g., online, word-of-mouth, etc.…
- Dealership sale
- Other list:

17) Hypothetically speaking, if you are selling a class 8 vehicle with 2 years/200,000 miles of remaining emission-related component warranty that covers everything related to the malfunction indicator light (MIL), how much more would you expect to get for a vehicle with the remaining emission warranty compared to one without it (the same production year, mileage, planned future use)? Please consider the vehicle class and fuel type that best represents your fleet.

- $0 - 999
- $1,000 – 1,999
- $2,000 – 2,999
- $3,000 – 4,999
- More than $5,000 (please specify)

18) Same as above (hypothetically speaking) but with 4 years/400,000 miles.

- $0 - 999
- $1,000 – 1,999
- $2,000 – 2,999
- $3,000 – 4,999
- $5,000 – 6,999
- $7,000 – 8,999
- More than $9,000 (please specify): $ ________________

For used vehicle purchasers:

19) What is your typical warranty type?

- CARB warranty (5 years / 100,000 miles)
- Base warranty provided by the manufacturer/dealer (Example: 2 years / 250,000 miles)
- Extended warranty provided by the manufacturer/dealer
- Aftermarket warranty provided by a third party
- Unsure
- Not applicable (please specify)

20) Where do you buy used vehicles from?

- Private sales (e.g., online or vehicle sales publications)
- Dealership sales

- Vehicle auction sales
- Other : ________________________________

21) Hypothetically speaking, if you are buying a used class 8 vehicle with 2 years/200,000 miles of remaining emission-related component warranty that covers everything related to the malfunction indicator light (MIL), how much of a higher price would you be willing to pay for the vehicle compared to one without it (the same production year, mileage, planned future use)? Please consider the vehicle class and fuel type that best represents your fleet/truck.

- $0 - 999
- $1,000 – 1,999
- $2,000 – 2,999
- $3,000 – 4,999
- More than $5,000 (please specify): $ ________________

22) Same as above (hypothetically speaking) but with 4 years/400,000 miles

- $0 - 999
- $1,000 – 1,999
- $2,000 – 2,999
- $3,000 – 4,999
- $5,000 – 6,999
- $7,000 – 8,999
- More than $9,000 (please specify): $ ________________

23) Do you typically purchase a longer warranty (offered by the manufacturer or a third-party provider)?

- Yes (go to "Longer Warranty Questions" section)
- No

DEALERSHIP QUESTIONS:

24) Please list the estimated percent of your vehicle sales by the Gross Vehicle Weight Ratings (GVWR) for class 4 through class 8 vehicle. Indicate the percent below with the total adding to 100.

- Greater than 33,000 lbs (Class 8): ________________
- 19,501 to 33,000 lbs (Class 6 and 7): ________________

- 14,000 to 19,500 lbs (Class 4 and 5): ___________________

25) Based on your customer experience, how long does the typical fleet keep their vehicles before replacing them?

- Sell before warranty runs out (If yes, go to 2-1)
- Keep until end of warranty period
- Keep until cost of repairs are excessive
- Keep until dependability becomes a problem
- Other (please specify): ____

26) If you answered, "Sell before warranty runs out", do they typically cash in the remaining warranty on the vehicles prior to selling them back to the dealer?

- Yes
- No
- Other (please describe)

27) After fleets start purchasing new vehicles having CARB's longer emissions warranties, do you expect fleets will operate the vehicles for a longer period before selling them?

- Yes
- No
- If your answer is "No" please briefly explain:______________________________________

28) Do you typically offer vehicles for sale that have remaining extended warranties that can then transfer to the new owner?

- Yes
- No
- If your answer is "No" please briefly explain:______________________________________

29) Hypothetically speaking, if you are selling two identical class 8 tractors that are the same production year, the same mileage, planned future use, but one has a remaining "manufacturer's emissions" warranty of **200,000 miles/2 years**, how much higher selling price would the vehicle with the warranty command compared to the one without?

- $0 - 999
- $1,000 – 1,999

- $2,000 – 2,999
- $3,000 – 4,999
- More than $5,000 (please specify): $______________

30) Same as above (hypothetically speaking) but **400,000 miles/4 years**

- $0 - 999
- $1,000 – 1,999
- $2,000 – 2,999
- $3,000 – 4,999
- $5,000 – 6,999
- $7,000 – 8,999
- More than $9,000 (please specify): $ ______________

#31 – 40: FLEET – For new & used vehicle purchasers.

E. Cummins' testimony from the August 27, 2020 board hearing

The entire transcript is available at https://ww3.arb.ca.gov/board/mt/2020/mt082720.pdf

From page 277 line 22 to page 279 line 19:

> MS. KENNEDY: Okay. Thank you. Chairwoman Nichols and members of the Board, thank you for the opportunity to provide comments today. My name is Melina Kennedy and I'm the Vice President of Product Compliance and Regulatory Affairs at Cummins. As a global power leader, Cummins is investing significantly in technologies, ranging from cleaner and more efficient diesel and natural gas, hybrids, battery electric, and fuel-cell electric powertrains, as well as hydrogen technologies.
>
> We understand the unique air quality issues California faces and we too are committed to improving the environment, while also delivering for our customers. To enable mutual success in these goals, we are recommending changes to the Heavy-Duty Omnibus Regulation outlined in detail in our written comments.
>
> Cummins has participated in industry discussions with CARB to explore the possibility of voluntary emission-wide NOx reductions. Despite good faith efforts by many, an agreement could not be reached, and as such Cummins plans to work toward meeting the proposed 2024. 0.05 gram NOx standard, which, at this point in time, will be extremely challenging.
>
> To eliminate regulatory uncertainty, we believe the 0.1 gram 50-state option in the proposal could be removed. Second, the incredibly short lead time for 2024 demands much more screen-lined pre-certification requirements for anyone to deliver on time.
>
> CARB's proposed durability and deterioration factor testing far exceed the time available in the manufacturer's product development schedule and should be revised.
>
> Third, we ask CARB not to finalize the proposed changes to emissions warranty reporting, corrective actions, warranty periods and useful life periods. Changing those requirements at the same time as introducing new technology will increase prices further and likely impact the adoption of those technologies in the market.
>
> We ask the Board to instead direct staff to conduct a comprehensive study to assess the cost and market implications of these potential changes and compare those to the impacts of other alternatives that achieve the same objectives.
>
> Cummins is committing to work with CARB to that end. We thank you for your time and your work, and this is just a summary of some of our suggested changes.
>
> Thank you.

F. ATA's comment on the draft report

AMERICAN TRUCKING ASSOCIATIONS
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www.trucking.org

August 13, 2021

California Air Resources Board
1001 I Street
Sacramento CA 95812

RE: **DRAFT Warranty cost study final report_072321 CLEAN**

Dear CARB staff and interested parties:

Thank you for the opportunity to review the draft document titled "DRAFT Warranty cost study final report_072321 CLEAN." ATA appreciates the time and effort involved in attempting to better understand the significant differences among the estimates contained in the various warranty cost studies. As noted in the report, "CARB staff and the work group members were unable to agree on all the elements of warranty cost estimation methods" (p. ES-11). Given the continuing disagreement over methodology and findings, ATA requests that CARB note this in the disclaimer (p. iv) and include stakeholder reviews as part of the final report. This will help to ensure industry concerns are documented and reflected in the final document.

With regard to the document itself, ATA offers the following observations and comments.

1. Beginning with CARB's 2018 rulemaking to extend the emission warranties of heavy-duty diesel trucks (Step 1), ATA has contended that CARB is underestimating the costs associated with extended warranties. One key assumptions is, "CARB staff's analysis considers that most owners either voluntarily purchase longer warranties beyond current regulatory requirements or are gifted them during the sales negotiation process (ISR, 2017)" (p. ES-3). As a result, CARB staff assumes that these "voluntarily purchased" or "gifted" warranties have zero financial cost and are essentially a free commodity. ATA disagrees with this assertion and notes when our members voluntarily purchase extended warranties, real dollars are spent and this transaction needs to be accounted for as part of the warranty analysis. Additionally, "gifted" warranties represent a cost to the manufacturer and should be similarly accounted for.

2. The document states, "Using CSUS survey data, CARB staff more accurately accounted for current warranty buying practices by fleets and owner/operators than the NREL/ACT Research/EMA's analyses and hence CARB staff's warranty baseline is higher than in the other analyses." (p. ES-7). Table III.A.2 indicates CARB staff assumes 85% of HDDVs are currently purchased with warranties that are longer than the regulatory requirements (p. 7).

   According to the CSUS survey,

   > Only a small percentage (24%) of owner/operators report having an extended warranty that provides protection beyond the mandatory coverage; however, for those that have an extended warranty, 84 percent report that it covers both parts and labor, with a wide

> variance of the number of additional miles covered (see Figures 12, 13, and 14). The majority of these extended warranties (60%) cost anywhere from $1,000 to $5,000 (see Figure 15). (CSUS, p. 9)

How CARB staff arrived at its assumption based on the survey findings is unclear. Further, the survey indicates only 12% of those who reported having an extended warranty received it for "free", likely a manufacturer-provided extended warranty (CSUS, p. 10). These survey results are inconsistent with the presented analysis.

3. CARB states, "The survey results indicated that the remaining residual warranties do in fact add value to vehicles sold in the secondary market, averaging approximately $2,000 for a 2 years/200,000 miles period of residual warranties, and $4,000 for a 4 years/400,000 miles residual period." (p. ES-8). Contrasting this statement with CARB's incremental cost estimate for Step 1 warranty of $285 per HHDD engine (p. ES-2) highlights the inconsistency of CARB's initial cost estimate.

4. The CARB staff analysis appears to continue to assume that manufacturers will choose to distribute costs evenly across product lines (FSOR, p. 19). This assumption has proven to be incorrect by the recent manufacturer surcharge notices that have been issued for Step 1. As indicated in these notices and CARB's own rulemaking, the extended warranty requirements only affect commercial vehicles registered for use in California. In addition, three additional "CARB Opt in" states are subject to these requirements. These surcharges, which are consistent with the manufacturers supplied cost estimates, are being applied to a subset of vehicles purchases rather than across product lines. Additionally, the mandatory, as opposed to voluntary, application of these extended warranties is subjecting these added warranty costs to the 12% federal excise tax.

While a substantial amount of time and effort has been spent analyzing the CARB staff assumptions and projections and receiving industry input, unfortunately, we do not believe this process has brought us any closer to agreeing on the additional cost impacts of mandatory extended warranties. The industry's experience with the Step 1 warranty is just playing out and truck buyers are experiencing higher costs when purchasing affected vehicles. These impacts are not adequately reflected in the analysis and, as a result, dilute the baseline being used for the prospective analysis.

We remain deeply concerned about the additional costs associated with the Step 1 and upcoming Step 2 warranties and will continue to evaluate their impacts on truck purchases going forward.

Sincerely,

Michael Tunnell

Michael Tunnell
Director, Energy and Environmental Affairs
American Trucking Associations

G. EMA's comment on the draft report

APPENDIX to California Air Resources Board (CARB) Staff Report on the Warranty Cost Study for 2022 and Subsequent Model Year Heavy-Duty Diesel Engines – EMA Remarks

The Truck and Engine Manufacturers Association ("EMA") represents the industry regulated under, and therefore most impacted by, the Omnibus Low NOx Rules. For that reason, and early on, EMA submitted a proposal to CARB Staff to co-fund a supplemental, independent, and rigorous reanalysis of the warranty-related costs that are likely to result from the implementation of the Omnibus regulations. Unfortunately, CARB Staff rejected that collaborative proposal, and instead elected to convene a Working Group to comment on the warranty-cost review that CARB Staff itself elected to undertake.

EMA participated in that Working Group, and has made a good faith effort to bring objective information and real warranty-cost data to the process. For its part, however, CARB Staff made it very clear from the outset that no changes would be made to the 2027 and 2031 model year emissions warranty requirements, no matter how significant any new warranty-cost information might be, or how the relevant cost-benefit ratios might change. As a result, and despite more than nine months of additional inputs and cost data, nowhere in this Report has Staff made any adjustments to any of the cost assumptions set forth in Staff's original Initial Statement of Reasons (ISOR) for the Omnibus Rule.

The Final Staff Report, as written, describes the various inputs submitted through the Working Group process, including inputs from EMA, and then offers Staff's defense of the original assumptions and significantly understated warranty costs set forth in the ISOR. In that regard, Staff made no revisions whatsoever to account for any of the new information that was submitted over the nine-month Working Group process. Consequently, the Report's conclusions do not actually reflect the consensus and results of a collaborative work group effort; they simply amount to Staff's rearticulation of the methods and warranty-cost assertions contained in the ISOR. Because of that non-collaborative outcome, EMA has requested to have these summary remarks included as an Appendix to the Report, to be sure that the actual cost data from the impacted industry are available to all stakeholders.

We are also providing the warranty cost estimates newly prepared by Ricardo PLC, an independent consulting group with a great deal of experience studying the cost impacts of emissions regulations. Significantly, Ricardo's estimates are for more in line with those of ACT Research and NREL, and project warranty costs more than an order of magnitude higher than CARB's.[3] More specifically, Ricardo estimates the incremental costs from CARB's 2031 warranty requirements for heavy heavy-duty diesel engines to be $16,268. EMA has provided the full Ricardo report to CARB Staff along with these comments.

[3] Both CARB and EPA were requested by EMA to be direct contributors to and co-funders of the Ricardo study to promote transparency and full consideration of all viewpoints, data, and information from the Agencies. Both EPA and CARB declined. EMA provided Ricardo with all relevant CARB rulemaking documents.

As noted, Staff's Report includes a number of explanations regarding why the warranty-cost projections made by researchers outside of CARB differ from Staff's, but does not provide an adequate explanation or justification as to *why* CARB Staff continue to hold to those original positions. Thus, many of CARB's methods and assumptions remain unjustified, especially in the face of the new information submitted to Staff. More specifically, EMA continues to have strong objections to many of the underlying assumptions that CARB has made in its warranty-cost assessment, including the following:

1. CARB does not report the full range of costs that the purchasers of heavy-duty trucks will be expected to bear as a result of the new emissions warranty requirements, including those that will be forced upon truck buyers that do not currently purchase extended warranties.

2. CARB assumes that the warranty costs associated with the $4,800 of new additional emissions-control hardware and componentry that will be needed to comply with the new Omnibus low-NOx emission standards will be *zero,* and summarily dismisses the historical precedent that those new emissions-control components likely will experience elevated failure rates during the first years of deployment.

3. CARB further assumes that none of the other significant requirements of the Omnibus Regulations -- including the new extremely stringent emission standards, the new extended Useful Life requirements, the new in-use testing protocols and standards, the new low-load certification requirements, and the new OBD provisions -- will have any significant impact on warranty costs.

None of those assumptions is reasonable, and they all are belied by the additional data and commentary that CARB Staff received from the regulated industry through the Working Group process. The net result is that Staff's assumptions regarding future warranty-related costs remain unreasonable and understated by an order of magnitude, as explained in further detail below.

CARB's methodology is based on the assumption that the unscreened warranty claims rates that have pertained over the most recent five-year period will be fully predictive of the warranty claims rates that will pertain to the new engines, aftertreatment systems, components and close-coupled packaging that will be required to comply with CARB's 2024 and 2027 model year standards over the significantly extended useful life and emissions warranty periods. (See, e.g., Report, pp. ES-1 and ES-5.) That assumption is not supported by the warranty-claims increases that have followed the initial implementation years of every prior rulemaking of this type, and does not comport with manufacturing practices and supplemental product improvements that are learned about and implemented after new stringent standards take effect. Moreover, CARB's assumption makes no separate accommodations for the increased componentry and complexity of the close-coupled multi-element aftertreatment systems that the new Omnibus standards will dictate. That is simply not reasonable. The multiple new requirements under the Omnibus Regulations are very different from what pertains today, with multiple new and different things that can go wrong, and with fundamentally different consequences if they do. It is for those reasons that EMA assumed a 20% higher emissions warranty claims rate during the initial years after the phase-in of CARB's 2024 and 2027 model year standards. CARB's complete disregard of that reality is, again, unreasonable.

CARB's methodology appears to use nationwide production volumes (not California-only production volumes) to dilute the per-vehicle/engine costs of CARB's extended emission warranty requirements. (See Report, pp. 20, 32-33.) That too is not reasonable. CARB's own regulations make clear (see, e.g. CCR Title 13, section 2035) that CARB's extended emissions warranty program will apply only to CARB-certified and California-registered vehicles up through the 2027 model year. CARB's analysis is fundamentally flawed in this regard.

Using nationwide production numbers, CARB assumes that the "Step 1" warranty costs will only amount to $285 per engine. (See Report, ES-1.) That assumption is belied by the actual cost numbers that OEMs have reported to CARB for the Step 1 warranties that they are providing for the 2022 MY pursuant to CARB's regulations (for example, manufacturers of 11-13L engines are currently charging, on average, approximately $2,500 for the extended "Step 1" warranty). CARB's disagreement with those actual, reported and publicly announced cost increases does not detract from the fact that the increased costs that OEMs have reported are **real** costs being passed on to **real** vehicle/engine purchasers starting with **real** product orders that are being processed now. CARB's continued assertion of assumed Step 1 cost increases in the face of countervailing actual cost information is manifestly unreasonable. The actual current cost data conclusively prove that CARB's warranty-cost assumptions are understated by an order of magnitude.

CARB's assumed emissions warranty baseline is **not** the current standard **regulatory** emissions warranty, but rather a hypothetical "average" **extended** warranty that various fleet operators might have elected to buy in the past. That is not a fair baseline to assess the impacts of moving from one **regulated** baseline to another. A hypothetical fleet operator's past calculus of whether to pay more in today's market for more miles of warranty coverage is not germane to an assessment of the actual baseline cost differential of moving the regulated emissions warranty requirements from one range of mileage/years to a much greater range of mileage/years in the future. That change in regulatory baselines has an ascertainable cost increase. Whether fleet operators have shown a past willingness to take on a portion of that cost increase does not reduce the overall ascertainable cost increase of changing the regulatory requirements; it simply reveals that the market likely will be inelastic enough to accommodate a portion of those costs without changing vehicle-purchasing decisions. CARB's use of that marginal inelasticity in demand to discount the actual cost impact of its extended warranty regulations is simply not justified or reasonable.

CARB's warranty-cost rationale is internally inconsistent. On the one hand, CARB assumes that an extended warranty of approximately 200,000 miles (moving from a regulated warranty of 100,000 miles to an extended regulated warranty of 350,000 miles) will only result in a cost increase of $285 per engine. Yet at the same time, CARB asserts that a residual emissions warranty of 200,000 miles would increase the resale value of a truck by $2,000. (See Report, ES-6.) This implies that a used vehicle purchaser is willing to pay nearly ten-times more than the actual cost of the residual warranty at issue. That does not add-up. One of CARB's numbers is off by a factor of ten. The relevant and established facts at issue reveal it to be CARB's inherently unreasonable $285 number, which, again, is understated by an order of magnitude.

EMA developed an additional approach to compare CARB's understated cost estimates against the more objective analyses of ACT Research, and now Ricardo. Before discussing that additional approach, it bears noting that Ricardo's methodology and cost estimates are based on the most exhaustive review of public data sources, estimation methods, industry input, and expert analysis conducted to date. Notwithstanding the rigor of Ricardo's study (which, again, is being submitted with these comments), EMA also undertook an additional approach of fact-checking CARB's unreasonable assumptions by using aftermarket warranty costs as a tool to estimate the costs that can reasonably be expected as a result of CARB's extended warranty requirements, based on *real, current business experience*. (CARB inaccurately refers to this supplemental analysis based on aftermarket warranty pricing as the "EMA estimate.")

CARB's review of the EMA analysis based on aftermarket warranty pricing is a clear example of CARB's effort to discount and dismiss new information, rather than incorporate it into reasonable and necessary adjustments to Staff's original cost projections. More specifically, CARB Staff present a "waterfall" breakdown of EMA's aftermarket-based analysis in Section III.E. of the Report, including Staff's rationalization for each progressive segment of their analysis, in Figure III.E.1, reproduced here:

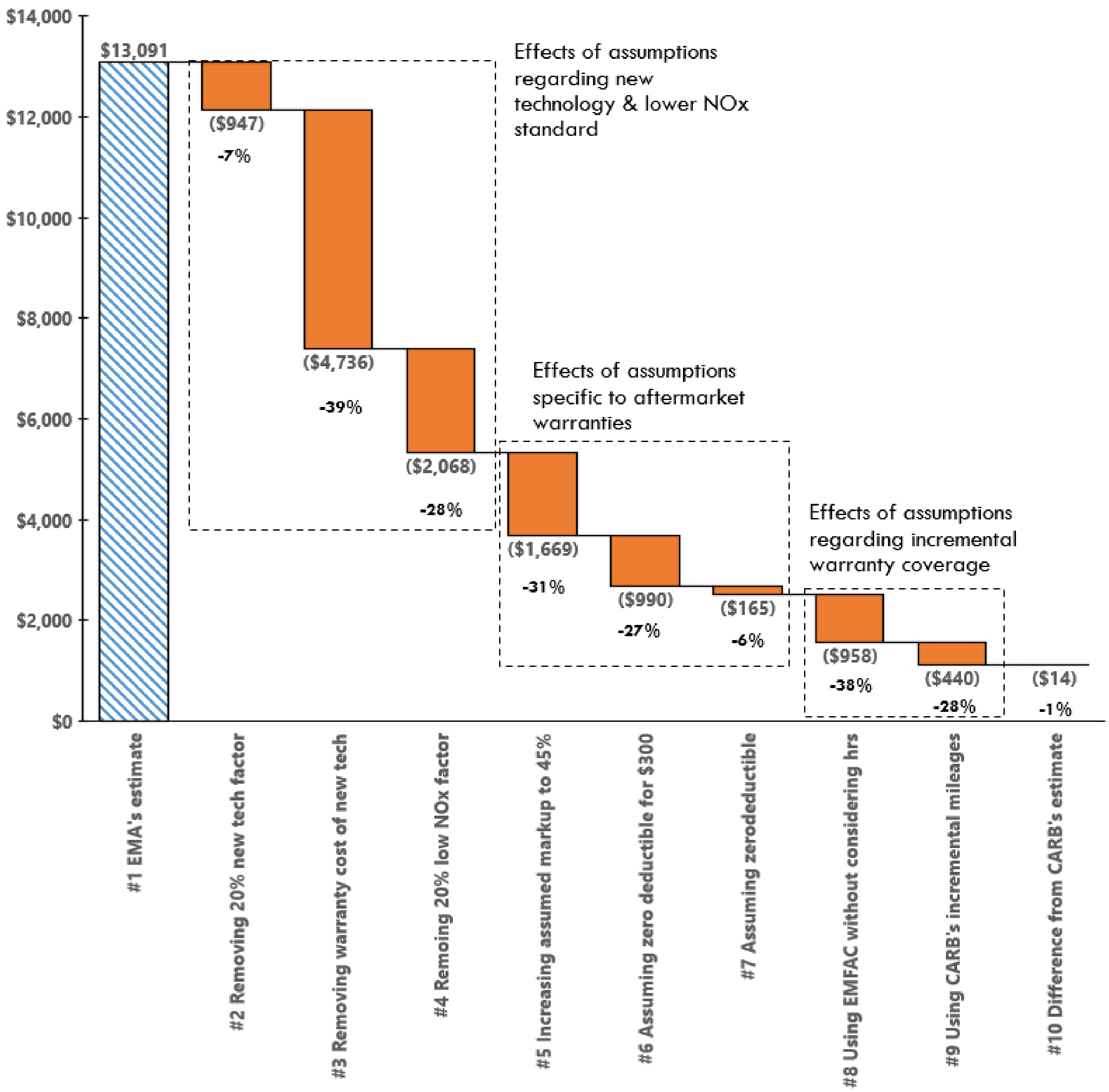

Figure III.E.1. Effects of different assumptions on EMA's warranty cost estimates. The x-axis label corresponds to scenarios in Table III.E.1.

There are multiple flaws with each of CARB's rationalizations in the figure above (CARB Staff's full explanations can be found on pages 28-31 of the Report). The counter-points below track the flow of CARB's "waterfall" in the figure above:

1) EMA's "estimate" (it is really an aftermarket-based analysis, as noted above) was put forward as a rationality check using the real-world aftermarket costs for extended warranties as a means for comparison with CARB's assumption-based estimates that are more than an order of magnitude lower. EMA did not establish the aftermarket warranty prices that show

the order-of-magnitude difference with CARB's numbers. Thus, it is a misnomer to refer to the $13,091 number as "EMA's estimate." It is a cost number derived from publicly available aftermarket warranty price information.

2) CARB chooses to ignore the historical precedent that major new emission-control technologies deployed on an accelerated regulatory timeline will experience elevated failure rates in the first few years after introduction.

3) The most egregious of the assumptions that CARB makes is that adding 50% more emissions-control componentry (on a cost basis), including close-coupled SCR and Cylinder Deactivation -- technologies never before applied above Class 3 vehicles and engines – will have absolutely no impact on the emissions warranty costs experienced on a heavy-duty truck. It should be noted that CARB is dismissing *all* of the warranty costs associated with those multiple new components from the first mile of operation. If the assumption instead is that the *combined* warranty costs from both existing and new technologies will not increase above today's levels, then that would mean that the warranty costs associated with existing components (most of them in production for one to two decades or more) would suddenly decrease by almost 50%, effective with the first introduction of Omnibus-compliant engines. Such an assumption is patently unreasonable.

4) CARB assumes that the replacement costs for existing emissions-related components will not increase despite their having to be re-designed to meet CARB's extended Useful Life requirements, despite the fact that OBD systems will illuminate the MIL more frequently when operating to ensure tailpipe emissions control to 10% of today's levels, and despite the fact that CARB's new warranty coverage will pertain to "*anything that illuminates the MIL.*" That cannot be and is not reasonable.

5) EMA made a projection that the companies that offer aftermarket warranties will look to make a marginal profit of approximately 20%. CARB rejected EMA's projection and claims that the profit margin should be assumed to be 45%, based on an article[4] that CARB found regarding the operation of third-party repair centers -- a completely different business and business model from aftermarket warranty providers. CARB's extrapolation from that one largely irrelevant article, as part of Staff's transparent maneuver to discount the underlying "real" costs of the extended warranties at issue, is emblematic of Staff's overall approach in preparing its Report.

6) CARB dismisses one of the revenue sources for the aftermarket warranty business balance sheet.

7) Same as #6.

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[4] https://www.fullbay.com/blog/heavy-truck-shop-parts-pricing/

8) While the new warranty limitations based on hours are a reasonable basis for considering the expiration of the extended emissions warranties, CARB makes no attempt to characterize separately the warranty costs of trucks that operate "on the clock" versus those that operate "on the odometer."

9) One of the most serious faults with CARB's economic assessment is its complete failure to reflect the likely cost impacts on the most heavily impacted truck buyers in California. CARB's attempt to assess the "average customer experience" is not a full assessment of the real-world cost impacts at issue.

10) CARB concludes its waterfall breakdown of the additional aftermarket-based warranty cost assessment that EMA provided by stating, "As a result, the warranty cost is further decreased to … $1,118, which agrees with CARB's estimate ($1,104) within 2 percent." The reality is that this purported "alignment" is observed only after applying the unreasonable cascade of assumptions that CARB has devised, as described above, which means that there is no actual alignment whatsoever. Moreover, CARB's efforts to defend its significantly under-estimated cost projections would mean that the purchasers of aftermarket warranties are consistently and repeatedly making extremely foolish business investments. EMA is confident that the trucking industry in California and elsewhere has a far better understanding of the real costs and benefits of doing business than does CARB.

As one more reality check of CARB's warranty-cost assessment, it should be noted that CARB applies its $0.01 (one cent) per-mile warranty cost estimate to each and every truck, regardless of application. More specifically, CARB applies this same estimate across all heavy heavy-duty engines and vehicles, including applications such as "T7 Utility" vehicles, which CARB assumes to have a 10-year accumulated mileage of 85,536 miles. CARB's estimation methodology would predict that the *total (from day 1)* emissions warranty costs encountered by that vehicle application *over a 10-year warranty period* would be approximately $855 – just $185 more than the cost to replace a single NOx sensor. Unreasonable outcomes such as this clearly illustrate the complete lack of rigor in CARB's cost-estimation process.

In sum, CARB's Report of its supplemental warranty cost assessment has disregarded the key input from engine and vehicle manufactures – input that includes the actual costs of Step 1 warranties -- in order to try to justify the extended warranty requirements of CARB's Omnibus Low-NOx Regulations. The calculation methods that CARB has utilized completely gloss over the real costs that will be incurred by the most heavily-impacted truck buyers. Consequently, while CARB's Report, in the end, attempts to ignore the Working Group process that Staff set up, it does not and cannot change what stakeholders have known about CARB's warranty cost estimates from the outset – they were and remain understated by an order of magnitude.

H. CARB staff's response to stakeholder comments on the draft report

(a) Comments from ATA

(a).1. Comment: … As a result, CARB staff assumes that these "voluntarily purchased" or "gifted" warranties have zero financial cost and are essentially a free commodity. ATA disagrees with this assertion and notes when our members voluntarily purchase extended warranties, real dollars are spent and this transaction needs to be accounted for as part of the warranty analysis. Additionally, "gifted" warranties represent a cost to the manufacturer and should be similarly accounted for.

Response: CARB staff does not assume voluntary warranties have zero financial cost. They are considered as the baseline cost. This report shows the incremental cost per new engine as a result of the rulemaking.

13 CCR 2036(c)(4)(A) equates emissions warranty with the base warranty period provided by the manufacturer with or without additional costs:

> (4)(A) In the case of diesel-powered heavy-duty vehicles greater than 14,000 pounds GVWR which are equipped with 2021 and prior model year motor vehicle engines, and motor vehicle engines used in such vehicles, a period of use of five years, 100,000 miles, or 3000 hours of operations, whichever first occurs. However, in no case may this period be less than the basic mechanical warranty that the manufacturer provides (with or without additional charge) to the purchaser of the engine. Extended warranties on select parts do not extend the emissions warranty requirements for the entire engine but only for those parts. In cases where responsibility for an extended warranty is shared between the owner and the manufacturer, the emissions warranty shall also be shared in the same manner as specified in the warranty agreement.

(a).2. Comment: According to the CSUS survey,

> Only a small percentage (24 percent) of owner/operators report having an extended warranty that provides protection beyond the mandatory coverage; however, for those that have an extended warranty, 84 percent report that it covers both parts and labor, with a wide variance of the number of additional miles covered (see Figures 12, 13, and 14). The majority of these extended warranties (60 percent) cost anywhere from $1,000 to $5,000 (see Figure 15). (CSUS, p. 9)

How CARB staff arrived at its assumption based on the survey findings is unclear. Further, the survey indicates only 12 percent of those who reported having an extended warranty received it for "free", likely a manufacturer-provided extended warranty (CSUS, p. 10). These survey results are inconsistent with the presented analysis.

Response: The 24 percent value includes used vehicles without extended warranties or with expired extended warranties and is not directly applicable to our baseline for new vehicles. CARB determined the warranty purchase practices based on the combination of the CSUS survey data (screened only for new vehicles) and CBI from OEMs. In a letter to CARB dated August 1, 2017, EMA estimated that 50 percent of new Heavy Heavy-Duty truck purchases include 5 year/500,000 mile extended warranties (CARB Staff Report Reference #59 - EMA, 2017). CARB elected to use 40 percent to be more conservative. The cost of the extended warranty is part of the baseline cost.

(a).3. Comment: CARB states, "The survey results indicated that the remaining residual warranties do in fact add value to vehicles sold in the secondary market, averaging approximately $2,000 for a 2 years/200,000 miles period of residual warranties, and $4,000 for a 4 years/400,000 miles residual period." (p. ES-8). Contrasting this statement with CARB's incremental cost estimate for Step 1 warranty of $285 per HHDD engine (p. ES-2) highlights the inconsistency of CARB's initial cost estimate.

Response: These numbers are conceptually different quantities. The former represents an increase in resale value based on remaining warranty, whereas the latter is the averaged incremental cost for Step 1 warranties after factoring in that 85 percent of new heavy-duty trucks are historically covered by extended warranties purchased separately or provided without additional cost. 13 CCR 2036(c)(4)(A) equates emissions warranty with the base warranty period provided by the manufacturer with or without additional costs. Therefore, CARB staff did not believe it appropriate to include the costs of current de facto warranty periods for the same coverage in Step 1.

(a).4. Comment: The CARB staff analysis appears to continue to assume that manufacturers will choose to distribute costs evenly across product lines (FSOR, p. 19). This assumption has proven to be incorrect by the recent manufacturer surcharge notices that have been issued for Step 1.

Response: Pg. 4 indicates that CARB's method does not assume even costs across product lines. It is based on all the unscreened warranty claim data for the recent five years. If a certain product line has higher claim rates, it is reflected in the average claim rates. Staff estimated average repair costs for individual engine and aftertreatment components by analyzing repair shop data and through discussions with manufacturers and service providers. We cannot predict the behavior of every manufacturer.

(a).5. Comment: … As indicated in these notices and CARB's own rulemaking, the extended warranty requirements only affect commercial vehicles registered for use in California. In addition, three additional "CARB Opt in" states are subject to these requirements. These surcharges, which are consistent with the manufacturers supplied cost estimates, are being applied to a subset of vehicles purchases rather than across product lines. Additionally, the mandatory, as opposed to voluntary, application of these extended warranties is subjecting these added warranty costs to the 12 percent federal excise tax.

Response: California emissions warranty coverage would be expanded to California-certified vehicles with California-certified engines, even if they are registered outside California, beginning with the 2027 MY. CARB's estimate does not include the federal excise tax.

(b) Comments from EMA

(b).1. Comment: … CARB Staff made it very clear from the outset that no changes would be made to the 2027 and 2031 model year emissions warranty requirements, no matter how significant any new warranty-cost information might be, or how the relevant cost-benefit ratios might change.

Response: CARB staff disagree with the comment. The Board directed staff to convene the work group to get a better understanding of the different cost methodologies not to change the warranty requirements.

CARB staff believe the methodology used to support the Omnibus Regulation warranty-related cost estimates is reasonable and defensible, and based on what was learned further in this study, we do not believe changes to those estimates are needed.

(b).2. Comment: … Staff made no revisions whatsoever to account for any of the new information that was submitted over the nine-month Working Group process. Consequently, the Report's conclusions do not actually reflect the consensus and results of a collaborative work group effort; they simply amount to Staff's rearticulation of the methods and warranty-cost assertions contained in the ISOR.

Response: Again, the purpose for conducting this study was to better understand the differences between CARB staff's estimates of warranty cost and those provided by industry stakeholders. CARB staff listened to stakeholder concerns. One action was the analysis of the warranty cost of new technologies. In response to the EMA's comments, CARB staff performed an additional sensitivity analysis evaluating the assumption of the warranty costs for new technology and estimated that if the warranty costs for new technology were included, it would increase the estimate of Omnibus regulatory costs by about 11 percent. The hypothetical increase was well within the bound of the previous CARB Staff Report sensitivity analysis that incorporated the incremental warranty costs from the NREL report (CARB, 2020; see chapter IX.F). Therefore, staff concluded that even if higher warranty cost estimates due to new technologies were included, it would not have changed the staff proposal. More details of the additional analysis are shown in Appendix I.

CARB staff will include the EMA's summary remarks as an Appendix to the report as requested.

(b).3. Comment: We are also providing the warranty cost estimates newly prepared by Ricardo PLC, an independent consulting group with a great deal of experience studying the cost impacts of emissions regulations.[…] EMA has provided the full Ricardo report to CARB Staff along with these comments.

Response: EMA did not provide CARB staff with the full Ricardo report but instead provided Ricardo's slide deck summarizing the report. Detailed analysis of Ricardo's method is beyond the scope of this study as it was shared to CARB staff beyond the scheduled 9-month period and after this draft Heavy-Duty Warranty Cost Study Report was completed.

It appears that Ricardo's method is based on confidential incremental cost information provided by OEMs, and therefore details of warranty cost estimation methods are unknown.

(b).4. Comment: … EMA continues to have strong objections to many of the underlying assumptions that CARB has made in its warranty-cost assessment, including the following:

1. CARB does not report the full range of costs that the purchasers of heavy-duty trucks will be expected to bear […].
2. CARB assumes that the warranty costs associated with the $4,800 of new additional emissions-control hardware and componentry that will be needed to comply with the new Omnibus low-NOx emission standards will be zero, and summarily dismisses the historical precedent that those new emissions-control components likely will experience elevated failure rates during the first years of deployment.
3. CARB further assumes that none of the other significant requirements of the Omnibus Regulations […] will have any significant impact on warranty costs.

Response: Detailed responses are discussed in the report. A properly engineered technology package designed to be durable throughout its useful life should not have more unforeseen production errors (per mile) than current packages designed to last for 435,000 miles. The emissions defects warranty requirements are not meant to compensate for improper engineering on the part of the manufacturer, but rather to protect the consumer (and air quality) from incorrect installations or material defects leading to premature failure. The occurrence of such defects is not expected to occur at higher rates than for current production vehicles because of CARB's amendments.

Regarding the second point on the warranty cost of new technologies, refer to comment (b).2.

(b).5. Comment: CARB's methodology is based on the assumption that the unscreened warranty claims rates that have pertained over the most recent five-year period will be fully predictive of the warranty claims rates that will pertain to the new engines, aftertreatment systems, components and close-coupled packaging that will be required to comply with CARB's 2024 and 2027 model year standards over the significantly extended useful life and emissions warranty periods. […] That assumption is not supported by the warranty-claims increases that have followed the initial implementation years of every prior rulemaking of this type, and does not comport with manufacturing practices and supplemental product improvements that are learned about and implemented after new stringent standards take effect.

Response: CARB staff extrapolated the most recent five-year data starting from 2013 MY to Step 2 warranty because most emission-related components expected for meeting the Omnibus standards would be similar to the existing technology that's currently on engines now. Some changes, such as heated dosing, are new, but CARB staff considers these changes to be evolutionary not revolutionary. Additionally, we expect that parts are less likely to fail because of continued improvement since 2013.

(b).6. Comment: Moreover, CARB's assumption makes no separate accommodations for the increased componentry and complexity of the close-coupled multi-element aftertreatment systems that the new Omnibus standards will dictate. That is simply not reasonable. The multiple new requirements under the Omnibus Regulations are very different from what pertains today, with multiple new and different things that can go wrong, and with fundamentally different consequences if they do. It is for those reasons that EMA assumed a 20 percent higher emissions warranty claims rate during the initial years after the phase-in of CARB's 2024 and 2027 model year standards. CARB's complete disregard of that reality is, again, unreasonable.

Response: Similarly, this is addressed in pg. 27-28 of this report. A properly engineered technology package designed to be durable throughout the longer useful life would not require higher defect warranty claim rates. Research & development cost for engineering should not be part of the defects warranty cost. Manufacturers may petition the Executive Officer to relax maintenance intervals should durability issues arise during the demonstration testing required for certification.

(b).7. Comment: CARB's methodology appears to use nationwide production volumes (not California-only production volumes) to dilute the per-vehicle/engine costs of CARB's extended emission warranty requirements. (See Report, pp. 20, 32-33.) That too is not reasonable. CARB's own regulations make clear (see, e.g., CCR Title 13, section 2035) that CARB's extended emissions warranty program will apply only to CARB-certified and California-registered vehicles up through the 2027 model year. CARB's analysis is fundamentally flawed in this regard.

Response: CARB's methodology uses CA-only production volume to calculate the statewide cost (see ISOR page IX-24).

Page 20 of the draft report states that "The California-only production volume can result in higher warranty costs due to higher unit prices if California-specific parts with small production volumes are used." Page 32-33 shows the table comparing CARB/NREL/ACT/EMA's methodology with footnotes for NREL/ACT that their estimates use CA-only volume, whereas CARB's column did not have the same footnote. EMA may have misinterpreted these to conclude CARB uses nationwide production volume.

CARB's methodology is based on the extrapolation of historical repair data. Although CA-only
production volume may contribute to higher unit prices, as stated in page 27, CARB's method assumed that potential increase in unit prices of emission-related components will be offset by gradual improvement in existing technology (e.g., early detection of failures by OBD).

(b).8. <u>Comment</u>: …CARB assumes that the "Step 1" warranty costs will only amount to $285 per engine. (See Report, ES-1.) That assumption is belied by the actual cost numbers that OEMs have reported to CARB for the Step 1 warranties that they are providing for the 2022 MY pursuant to CARB's regulations (for example, manufacturers of 11-13 L engines are currently charging, on average, approximately $2,500 for the extended "Step 1" warranty).

<u>Response:</u> As described in the report, although the details of OEMs' estimation methods are unknown, most of the difference between $285 and $2,500 may be explained by the different baselines and treatment of the miles covered under warranty. In CARB's method, miles covered under warranty increase only by 32,100 miles for Step 1 warranty, whereas OEMs may be budgeting assuming 250,000 miles increase in coverage (going from 100,000 to 350,000 miles).

(b).9. <u>Comment</u>: CARB's assumed emissions warranty baseline is not the current standard regulatory emissions warranty, but rather a hypothetical "average" extended warranty that various fleet operators might have elected to buy in the past. That is not a fair baseline to assess the impacts of moving from one regulated baseline to another. A hypothetical fleet operator's past calculus of whether to pay more in today's market for more miles of warranty coverage is not germane to an assessment of the actual baseline cost differential of moving the regulated emissions warranty requirements from one range of mileage/years to a much greater range of mileage/years in the future. […]

<u>Response:</u> CARB staff believe it is reasonable to include voluntary longer warranties to the baseline because those fleet operators who elected to purchase longer warranties in the past will experience less cost increase as a result of the rulemaking. Furthermore, 13 CCR 2036(c)(4)(A) equates emissions warranty with the base warranty period provided by the manufacturer with or without additional costs. Therefore, CARB did not believe it appropriate to include the costs of current de facto warranty periods for the same coverage in Step 1. The cost of the status quo is clearly not part of the incremental cost.

(b).10. Comment: CARB's warranty-cost rationale is internally inconsistent. On the one hand, CARB assumes that an extended warranty of approximately 200,000 miles (moving from a regulated warranty of 100,000 miles to an extended regulated warranty of 350,000 miles) will only result in a cost increase of $285 per engine. Yet at the same time, CARB asserts that a residual emissions warranty of 200,000 miles would increase the resale value of a truck by $2,000. (See Report, ES-6.) This implies that a used vehicle purchaser is willing to pay nearly ten-times more than the actual cost of the residual warranty at issue. That does not add-up. One of CARB's numbers is off by a factor of ten. The relevant and established facts at issue reveal it to be CARB's inherently unreasonable $285 number, which, again, is understated by an order of magnitude.

Response: Those two numbers are conceptually different. $285 is the average incremental cost accounting for those who voluntarily purchase longer warranties or who are gifted them in extended base packages or through negotiations. CARB staff estimated that the increase in miles covered under warranty in Step 1 is only 32,100 miles. $2,000 is an individual cost (not an average of the entire vehicles). On a per-mile basis, those two numbers are both approximately 1 cent/mile.

(b).11. Comment: EMA developed an additional approach to compare CARB's understated cost estimates against the more objective analyses of ACT Research, and now Ricardo. Before discussing that additional approach, it bears noting that Ricardo's methodology and cost estimates are based on the most exhaustive review of public data sources, estimation methods, industry input, and expert analysis conducted to date. Notwithstanding the rigor of Ricardo's study (which, again, is being submitted with these comments), EMA also undertook an additional approach of fact-checking CARB's unreasonable assumptions by using aftermarket warranty costs as a tool to estimate the costs that can reasonably be expected as a result of CARB's extended warranty requirements, based on real, current business experience. (CARB inaccurately refers to this supplemental analysis based on aftermarket warranty pricing as the "EMA estimate.")

Response: CARB staff has edited the report language from "EMA estimate" to "EMA's analysis using aftermarket warranty pricing". EMA did not provide the actual report to CARB staff but rather Ricardo's slide deck summarizing the report. Detailed analysis of Ricardo's method is beyond the scope of this study as it was shared to CARB staff beyond the scheduled 9-month period after this report had been drafted.

(b).12. Comment: 1) … Thus, it is a misnomer to refer to the $13,091 number as "EMA's estimate." It is a cost number derived from publicly available aftermarket warranty price information.

Response: CARB staff has changed "EMA estimate" to "EMA's analysis using aftermarket warranty pricing".

(b).13. Comment: 2) CARB chooses to ignore the historical precedent that major new emission-control technologies deployed on an accelerated regulatory timeline will experience elevated failure rates in the first few years after introduction.

Response: CARB staff did not include elevated failure rates because most emission-related components expected to meet the Omnibus standards would be similar to the existing technology that's currently on engines now. Some changes, such as heated dosing, are new, but CARB staff does not consider such changes as revolutionary. Additionally, we expect that parts are less likely to fail because of continued improvement in technology. Manufacturers should be aware of durability challenges regarding their products with respect to a change in standards prior to certification and apply for relaxed maintenance intervals for new technology durability issues rather than rely on the warranty provisions for this purpose. CARB staff also addressed EMA's concern in (b).2.

Also, the Omnibus ISOR performed a sensitivity analysis showing that the overall cost-effectiveness would still be reasonable even when much higher warranty costs (using NREL's survey) were incorporated.

(b).14. Comment: 3) The most egregious of the assumptions that CARB makes is that adding 50% more emissions-control componentry (on a cost basis), including close-coupled SCR and Cylinder Deactivation -- technologies never before applied above Class 3 vehicles and engines – will have absolutely no impact on the emissions warranty costs experienced on a heavy-duty truck. It should be noted that CARB is dismissing all of the warranty costs associated with those multiple new components from the first mile of operation. If the assumption instead is that the combined warranty costs from both existing and new technologies will not increase above today's levels, then that would mean that the warranty costs associated with existing components (most of them in production for one to two decades or more) would suddenly decrease by almost 50%, effective with the first introduction of Omnibus-compliant engines. Such an assumption is patently unreasonable.

Response: These points are discussed in pg. 27-28 of the draft report. A properly engineered technology package designed to be durable throughout its useful life should not have more unforeseen production errors (per mile) than current packages designed to last for 435,000 miles. Research & development cost for engineering should not be part of the defects warranty cost. Manufacturers should be aware of durability challenges prior to certification and apply for relaxed maintenance intervals for new technologies rather than rely on the warranty provisions for this purpose.

As described in the response to comment (b).2, an additional analysis on the potential impact of the warranty costs for new technologies is shown in Appendix I.

(b).15. Comment: 4) CARB assumes that the replacement costs for existing emissions-related components will not increase despite their having to be re-designed to meet CARB's extended Useful Life requirements, despite the fact that OBD systems will illuminate the MIL more frequently when operating to ensure tailpipe emissions control to 10% of today's levels, and despite the fact that CARB's new warranty coverage will pertain to "anything that illuminates the MIL." That cannot be and is not reasonable.

Response: Refer to the response to comment (b).14. MIL-related cost is included in CARB's estimate.

(b).16. Comment: 5) EMA made a projection that the companies that offer aftermarket warranties will look to make a marginal profit of approximately 20%. CARB rejected EMA's projection and claims that the profit margin should be assumed to be 45%, based on an article that CARB found regarding the operation of third-party repair centers -- a completely different business and business model from aftermarket warranty providers. CARB's extrapolation from that one largely irrelevant article, as part of Staff's transparent maneuver to discount the underlying "real" costs of the extended warranties at issue, is emblematic of Staff's overall approach in preparing its Report.

Response: Since the actual profit margin used by the aftermarket provider is unknown, the intent here is to understand the sensitivity of EMA's cost analysis on the assumed profit margin of 20 percent. CARB's reference to the Fullbay article in the Step 1 staff report does not maintain that the warranty costs should be increased by 45 percent, but uses this figure to project the possible upward range of warranty costs assuming manufacturers increase the costs of warranty packages for profit margin.

(b).17. Comment: 6) CARB dismisses one of the revenue sources for the aftermarket warranty business balance sheet.

Response: The intent here is to understand the sensitivity of EMA's cost analysis on the assumed deductible costs. CARB staff used information provided by J.D. Power ($0 deductible for $300) for evaluating this scenario.

(b).18. Comment: 7) Same as #6.

Response: Again, the intent here is to understand the sensitivity of EMA's cost analysis on the assumed deductible costs.

(b).19. Comment: 8) While the new warranty limitations based on hours are a reasonable basis for considering the expiration of the extended emissions warranties, CARB makes no attempt to characterize separately the warranty costs of trucks that operate "on the clock" versus those that operate "on the odometer."

Response: CARB's method estimates the warranty cost of average vehicles in order to evaluate the total statewide costs and benefits of the rulemaking.

(b).20. Comment: 9) One of the most serious faults with CARB's economic assessment is its complete failure to reflect the likely cost impacts on the most heavily impacted truck buyers in California. CARB's attempt to assess the "average customer experience" is not a full assessment of the real-world cost impacts at issue.

Response: As discussed in the response to comment (b).19, CARB's method aims at estimating the total statewide costs and benefits of the rulemaking. Therefore, estimation of individual cost impacts for different truck buyers is beyond the scope of the analysis.

Since CARB's estimates of the warranty costs are for the average vehicles, the individual incremental costs can be above or below the average. However, caution must be taken when applying CARB's method to individual vehicle categories. CARB's method assumes a linear relationship between the "average" repair cost under the warranty periods and the "average" miles covered under warranty. The same incremental mileage value (e.g., 100,000 miles) has different cost impacts for high-mileage (i.e., high average speed) vehicles and low-mileage (i.e., low average speed) vehicles.

To calculate the "individual" incremental cost for each vehicle category, one would need an "individual" repair cost for each vehicle category (which was not available to CARB staff) and "individual" miles covered under warranty (which is available from the EMFAC model).

For example, in Step 1 warranty, the average miles covered under warranty increases from 316,010 miles to 348,172 miles, which is only a 10 percent increase (section III.A.2). However, the miles covered under warranty of a "T7 Single Construction" vehicle with only the current regulatory warranty (5 years/100,000 miles) would increase from 100,000 miles to 212,000 miles in MY 2022, which means that their repair costs would increase by a factor of 2.12 as a result of Step 1 warranty. Since the repair cost information specific to "T7 Single Construction" vehicle at the end of 5 year/100,000 miles is not available, absolute values of the individual cost impact cannot be quantified using CARB's method intended for the average vehicles.

(b).21. Comment: 10) CARB concludes its waterfall breakdown of the additional aftermarket-based warranty cost assessment that EMA provided by stating, "As a result, the warranty cost is further decreased to … $1,118, which agrees with CARB's estimate ($1,104) within 2 percent." The reality is that this purported "alignment" is observed only after applying the unreasonable cascade of assumptions that CARB has devised, as described above, which means that there is no actual alignment whatsoever.

Response: Again, the intent of the waterfall breakdown is to better understand how each of the different assumptions made by CARB and EMA contributes to the warranty cost discrepancy.

(b).22. Comment: Moreover, CARB's efforts to defend its significantly under-estimated cost projections would mean that the purchasers of aftermarket warranties are consistently and repeatedly making extremely foolish business investments. EMA is confident that the trucking industry in California and elsewhere has a far better understanding of the real costs and benefits of doing business than does CARB.

Response: CARB staff think our approach is reasonable given the unique circumstances of aftermarket warranties. For instance, aftermarket warranty providers may need to obtain parts from OEMs. Also, their customers may be disproportionately high-mileage drivers who accumulate mileages well over the current full useful life and expect frequent failures (because such drivers would be those who would be most likely to choose to buy an aftermarket warranty).

(b).23. Comment: As one more reality check of CARB's warranty-cost assessment, it should be noted that CARB applies its $0.01 (one cent) per-mile warranty cost estimate to each and every truck, regardless of application. More specifically, CARB applies this same estimate across all heavy heavy-duty engines and vehicles, including applications such as "T7 Utility" vehicles, which CARB assumes to have a 10-year accumulated mileage of 85,536 miles. CARB's estimation methodology would predict that the total (from day 1) emissions warranty costs encountered by that vehicle application over a 10-year warranty period would be approximately $855 – just $185 more than the cost to replace a single NOx sensor. Unreasonable outcomes such as this clearly illustrate the complete lack of rigor in CARB's cost-estimation process.

Response: This statement is incorrect. $0.01 per mile is an approximate average incremental cost calculated "after" considering different usage patterns of different vehicle subcategories in EMFAC. Using "T7 Utility" as an example, its baseline miles covered under warranty in MY 2022 is 46,656 miles and its endpoint miles covered under warranty in MY 2031 is 85,536 miles, which means their repair cost increase by a factor of 1.8 (i.e., 85,536/46,656).

(c) Comment from MEMA

(c).1. Comment: Given there is a learning curve when new technologies and/or new emission standards are phased-in, it is possible for more failures to result initially. CARB's warranty data from 2010 technology has shown that this is a transient phenomenon that declines to a stable level of failure rates after 2-3 years as the technology matures.

Response: Refer to the response to comment (b).13.

I. CARB staff's analysis of warranty costs for new technologies

As described in section IV.A (CARB's method in the Omnibus Regulation), CARB staff estimated the costs of Step 2 warranty by extrapolating the most recent five-year repair data into MY 2027/2031 conditions assuming a linear relationship between the average repair costs and the average miles covered under warranty.

Although there will be some new technologies introduced to meet MY 2027/2031 requirements, such as cylinder deactivation or light-off SCR, the technology changes are expected to be evolutionary rather than revolutionary and nearly all emission-related components expected for meeting the Omnibus standards would be the same as the technologies used today (DPF and SCR). CARB's methodology assumes there will be no net addition of repair costs per mile when those new technologies will be introduced because nearly all emission-related components expected for meeting the Omnibus standards would be the same as the existing technology that is currently on engines now, and because existing components will be less likely to fail because of continued improvement since 2013.

Through the work group meetings, EMA expressed their concern regarding this assumption for new technologies (see EMA's comments in section XI.G). In response to the comment, CARB staff performed an additional sensitivity analysis to determine the potential increase in cost if additional warranty costs for new technologies were accounted for.

1. Per-vehicle cost impact

In CARB's method, the baseline repair cost was calculated using the repair cost (including parts and labor) and unscreened warranty claim rate of each emission-related component. In this analysis of the warranty costs for new technologies, CARB staff used the incremental technology costs based on NREL's survey (CARB, 2020; Appendix C-3). The labor cost information was obtained through Step 1 warranty rulemaking (CARB, 2018; references #39 and #81). The unscreened warranty claim rates are taken from the five-year EWIR data for MY 2013 shown in Table IV.A.8 when relevant data are available, otherwise the average warranty claim rate of Table IV.A.8 (i.e., 4.2 percent) was used. As shown in Table XI.1, if the repair costs for the new technologies were included, it would increase the baseline repair cost by $445 from $2,416 (see section IV.A.3.(a)), i.e., 18.4 percent increase. In other words, if the repair costs for new technologies were included without changing the warranty periods, the repair costs would increase by 18.4 percent.

Table XI.1 Estimated incremental technology costs, labor costs, unscreened warranty claim rates, and repair costs per HHDD engine meeting MY 2027 and 2031 requirements

Technologies	Adjusted incremental cost based on NREL survey[a]	Assumed labor	Assumed warranty claim rate	Weighted average repair cost
Cylinder Deactivation	$1,097	$400[b]	4.2%[c]	$62
Other: Engine technology	$932	$400[b]	4.2%[c]	$56
Light-off SCR	$1,256	$300	1.3%[d]	$20
DOC	$125	$0	8.1%[e]	$10
DPF	$38	$0	1.1%[e]	$0
SCR + ASC and DEF Dosing System	$1,079	$300	5.3%[f]	$72
OBD Sensors and Controllers (NOx, NH3, and Temp Sensors)	$611	$200	22.2%[g]	$180
Other: Aftertreatment technology	$667	$400[b]	4.2%[c]	$45
Total	$5,803	-	-	**$445**

a. Adjustment is done by interpolating NREL's survey results for 435,000 miles and 1,000,000 miles at 800,000 miles.
b. Assumed average labor cost (based on data readily available to staff) when relevant data is not available.
c. When relevant warranty claim rate data is not available, the average value for the entire 2013 MY warranty claim rates was used.
d. Assuming same failure rate as 2013 MY SCR
e. Based on 2013 MY data
f. Average of 2013 MY SCR and DEF doser data
g. Average of 2013 MY NOx sensor and other sensors

The next step is to account for the longer warranty periods of Step 2 warranty. The average miles covered under warranty for HHDD engines in MY 2022 and MY 2031 are 288,710 miles and 399,843, respectively. Using the ratio of the miles covered under warranty, the hypothetical repair cost that includes new technologies is estimated to be $3,963 (i.e., $2,861 * 399,843/288,710). Since the baseline repair cost is $2,416, the incremental repair cost is $1,547 (i.e., $3,963-$2,416). By accounting for the finance cost (6 percent, five-year loan), the resulting warranty cost would be $1,836 as shown in Table XI.2. Figure XI.1. graphically represents the same procedure for estimating the incremental repair costs.

Table XI.2 Estimated impact of new technologies on warranty cost per HHDD engine in MY 2031

	Baseline miles covered under warranty in MY 2022	Baseline repair cost in MY 2022	Estimated miles covered under warranty beginning MY 2031	Estimated repair cost beginning MY 2031	Incremental repair cost beginning MY 2031	Finance cost (6%, 5-year loan)	Capital cost increase per vehicle beginning MY 2031
Omnibus ISOR	288,710	$2,416	399,843	$3,346	$930	$174	$1,104
New technology sensitivity analysis	288,710	$2,861	399,843	$3,963	$1,547	$289	$1,836

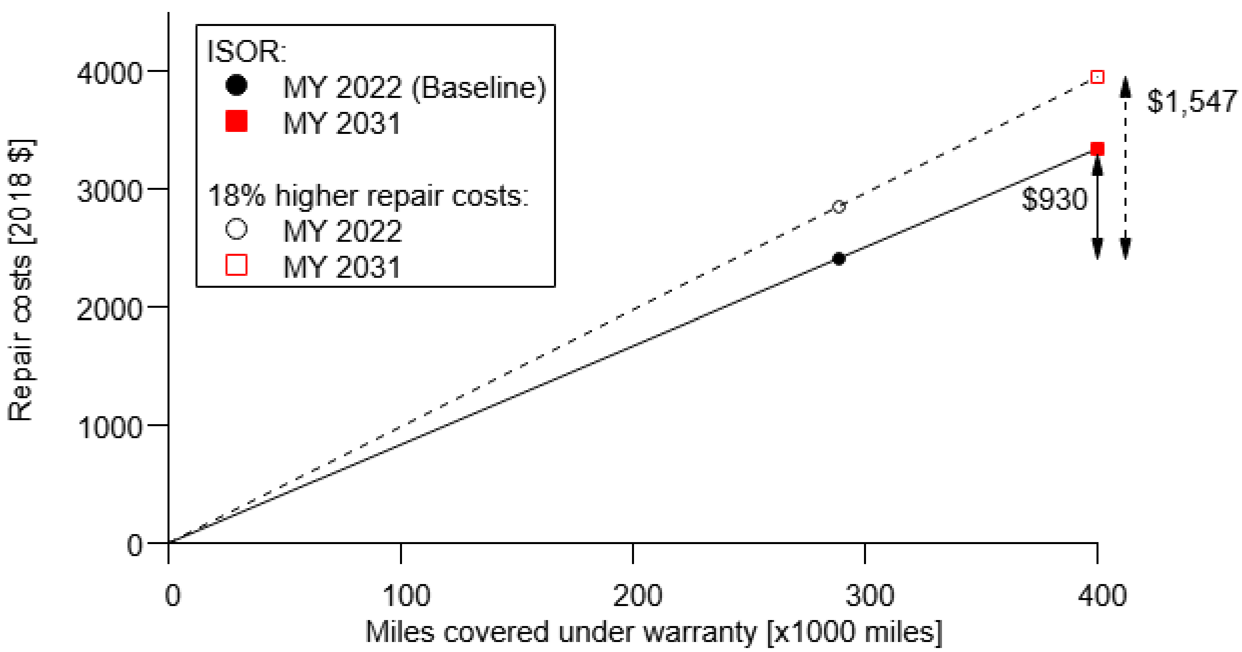


Figure XI.1 Estimated impact of new technologies on repair cost per HHDD engine in MY 2031

2. Statewide cost impact

To evaluate the potential impact of including the warranty costs for new technologies on the overall cost effectiveness of the Omnibus Regulation, for simplicity, the repair costs for all heavy-duty engines (HHDD, MHDD, LHDD, and HDO) are assumed to increase by 18.4 percent from MY 2027. Table XI.3 shows that if the warranty costs for new technologies were included (i.e., 18.4 percent higher repair costs per mile), it would increase the total cost of warranty (i.e., parts, labor, and finance costs) by 54 percent and the total cost of the Omnibus Regulation by 11 percent. Since the increased repair costs reflected on the purchase price would eventually be recouped as cost savings, the total savings of the Omnibus Regulation would increase by 49 percent. The total NOx benefit would stay the same. As a result, the cost effectiveness ($ per pound of NOx reduction) would increase by five percent.

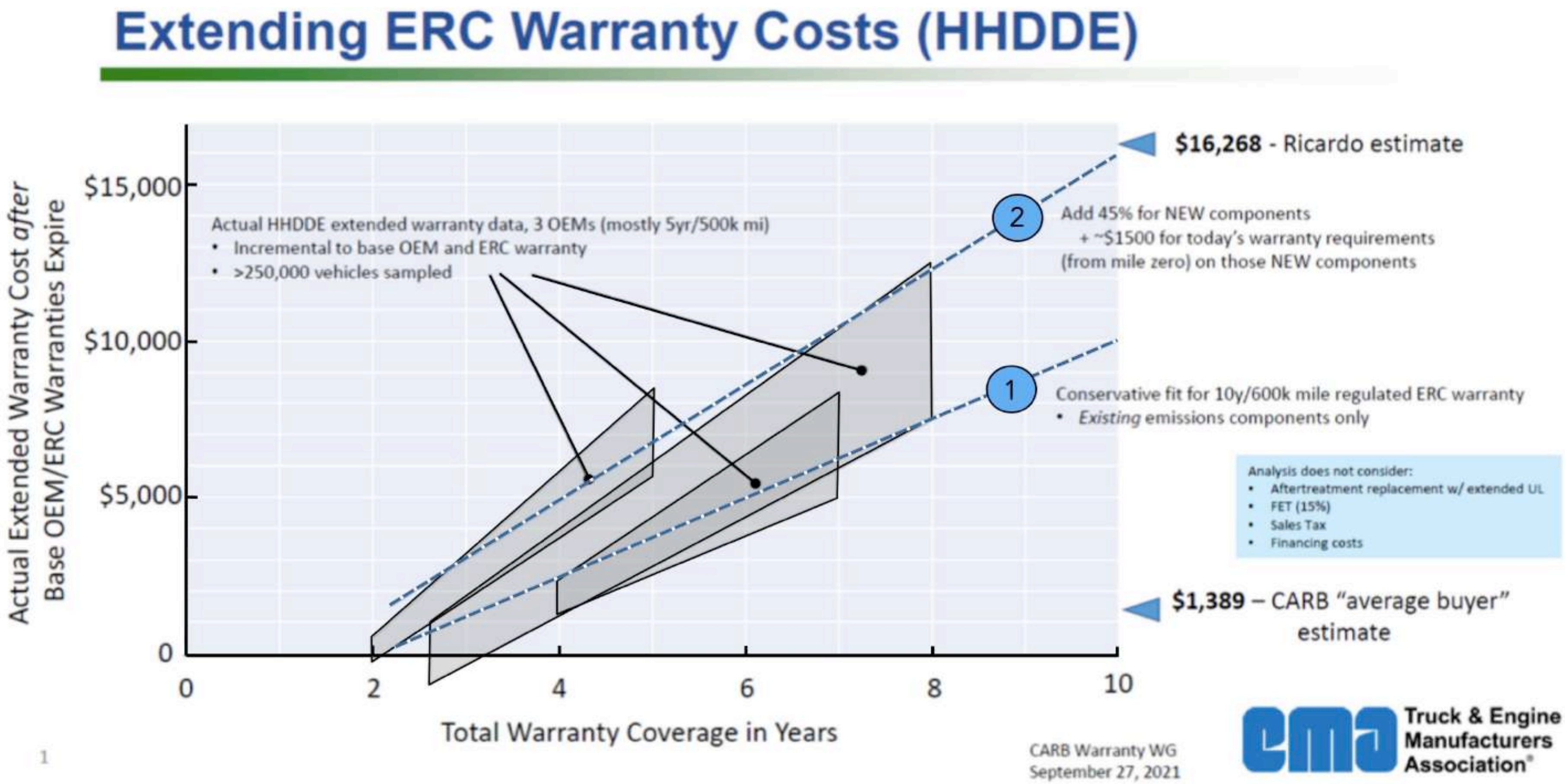
Table XI.3 Estimated impact of the warranty costs of new technologies on Omnibus Regulation's cost-effectiveness

Scenario	Total Cost of Warranty	Total Cost of Regulation	Total Savings of the Regulation	Total NOx Benefits [Tons]	Cost Effectiveness $/Ton	Cost Effectiveness $/lbs
ISOR	$933,280,923	$4,494,764,136	$650,574,767	352,797	10,896	5.45
Increasing repair costs by 18%	$1,435,433,020	$4,996,916,234	$970,336,830	352,797	11,413	5.71
Difference	$502,152,098	$502,152,098	$319,762,063	-	517	0.26

CARB staff compared the analysis result with the sensitivity analysis in the CARB staff report examining the impact of higher assumed warranty cost (CARB, 2020; Chapter IX.F). The CARB staff report sensitivity analysis showed that if the incremental warranty costs reported to the NREL survey were incorporated, it would have increased the cost effectiveness [$/lbs] by 26 percent (i.e., 6.88/5.45), which would still be reasonable when compared to those of recent CARB rulemakings. Since the five-percent increase is well within the bound of the previous CARB staff report sensitivity analysis (+26 percent), staff concluded higher warranty cost estimates due to new technologies would not have changed the staff proposal.

J. EMA's additional analysis "Projecting Extended Regulated ERC Warranty from Actual Extended Warranty Experience"

This analysis was presented to the work group by EMA staff on September 27, 2021. CARB staff was not provided the data it was based on and has not verified the analysis method.



CALIFORNIA AIR RESOURCES BOARD

Draft Advanced Clean Fleets Total Cost of Ownership Discussion Document

Advanced Clean Fleets Workshop

September 9, 2021

This document was prepared by California Air Resources Board (CARB or Board) staff to document the preliminary cost inputs and assumptions to be used for the economic analysis of the Advanced Clean Fleets regulation currently under development, as well as display the total cost of ownership of selected vehicles. This document is being released in advance of the Standardized Regulatory Impact Analysis (SRIA) and Initial Statement of Reasons (ISOR) for the Advanced Clean Fleets regulation to support stakeholder input and to provide the opportunity for staff to make revisions prior to publication of the SRIA and ISOR. Please send comments or cost information to the informal comment docket by September 27, 2021 to be considered prior to completion of the SRIA. Stakeholders can also continue to comment throughout the regulatory process.

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I. Table of Contents

II. Executive Summary

The zero-emission truck and bus market is growing rapidly, with over a hundred models commercially available today. Dozens of manufacturers, including established original equipment manufacturers and startups new to the heavy-duty market, have announced plans to release commercially available zero-emission vehicles (ZEVs). Zero-emission vehicles, including both battery-electric and fuel cell electric technologies, are the cleanest technology option and mass deployment is critical in achieving California's air quality and climate change goals.

This report assesses the total cost of ownership (TCO) of battery-electric and fuel cell electric vehicles versus their diesel, gasoline, and natural gas-powered counterparts. This report analyzes the key cost components that differ between these technology types including vehicle costs, fuel costs, maintenance costs, infrastructure investments, Low Carbon Fuel Standard (LCFS) revenue, and other costs. Six vehicle types were modeled in this analysis – a Class 2b cargo van, a Class 5 walk-in van, a Class 6 bucket truck, a Class 8 refuse packer, a Class 8 day cab tractor for use in drayage operations, and a Class 8 sleeper cab tractor. This analysis does not include any rebates, incentives, or grants to show how costs compare without the effect of subsidies.

In summary, the results show that battery-electric vehicles appear cost competitive with the established combustion technologies by 2025 in a variety of use cases. Significant savings are shown for battery-electric in the walk-in van, refuse truck, and day cab categories, even in the early years. Fuel cell electric vehicles also appear competitive with combustion-powered technologies in the 2025 to 2030 timeframe depending on the vehicle type. Despite the higher upfront costs associated with vehicle costs and infrastructure, cost savings from lower fuel costs and LCFS revenue result in a positive TCO. The TCO for ZEVs is expected to improve over time as costs continue to decline.

The following figures display the TCO for the six vehicle types in the three analysis periods.

Figure 1: Cargo Van TCO Comparison

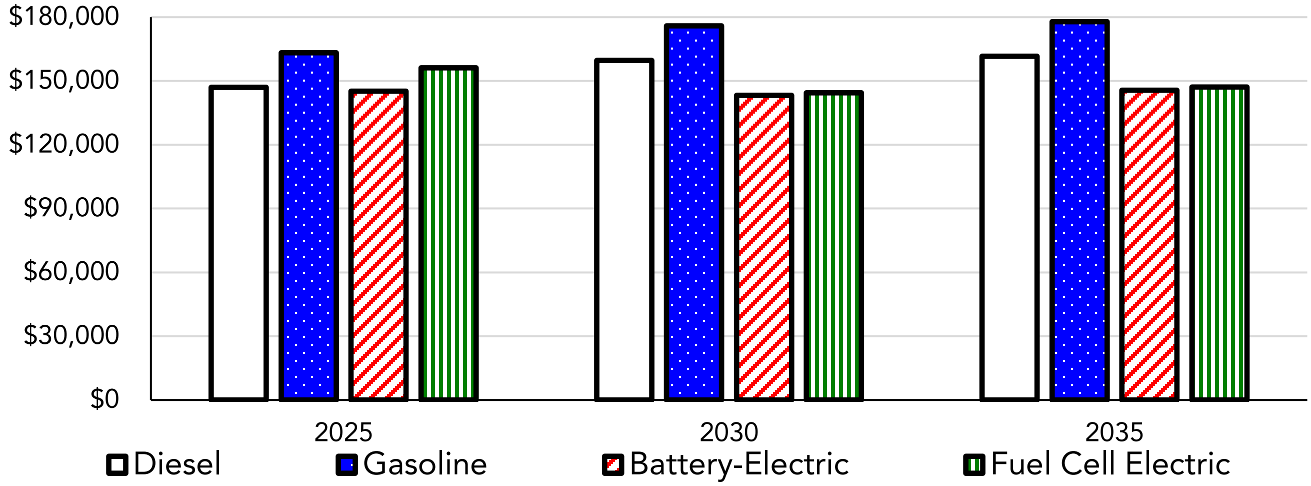


Figure 2: Walk-in Van TCO Comparison

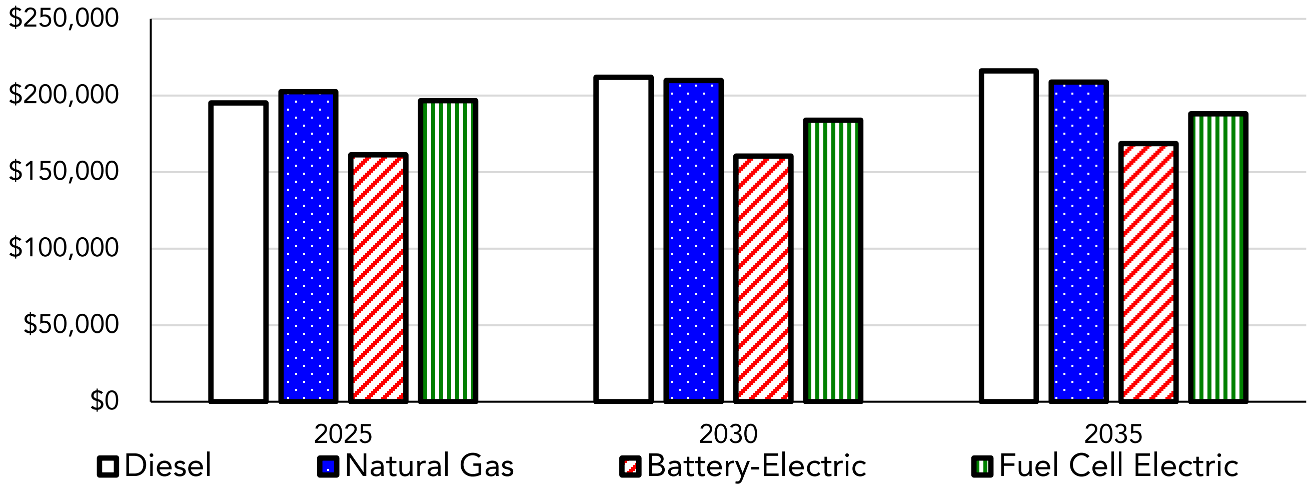


Figure 3: Bucket Truck TCO Comparison

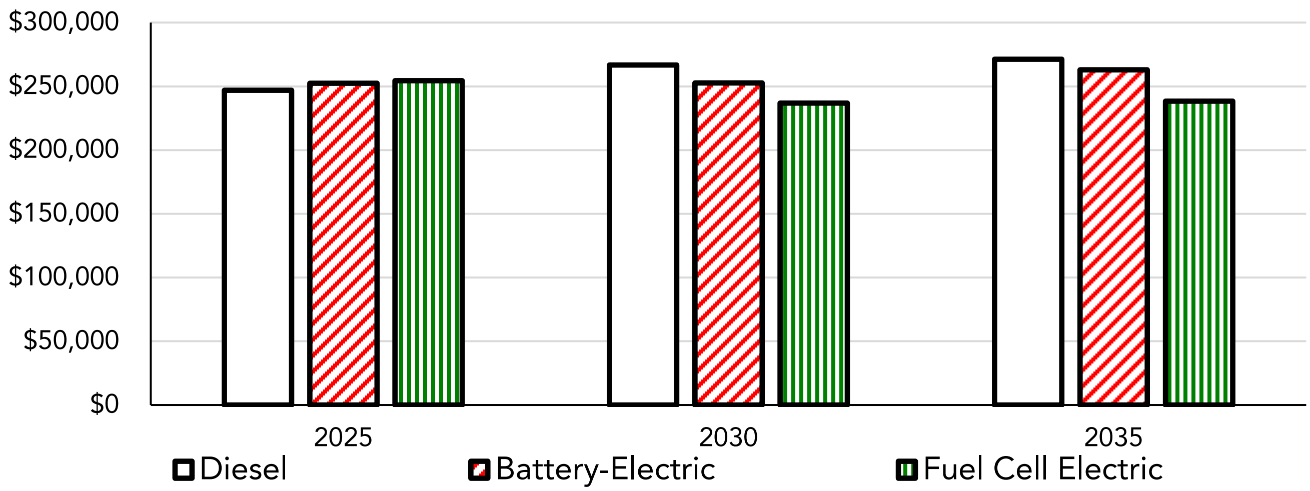


Figure 4: Refuse Truck TCO Comparison

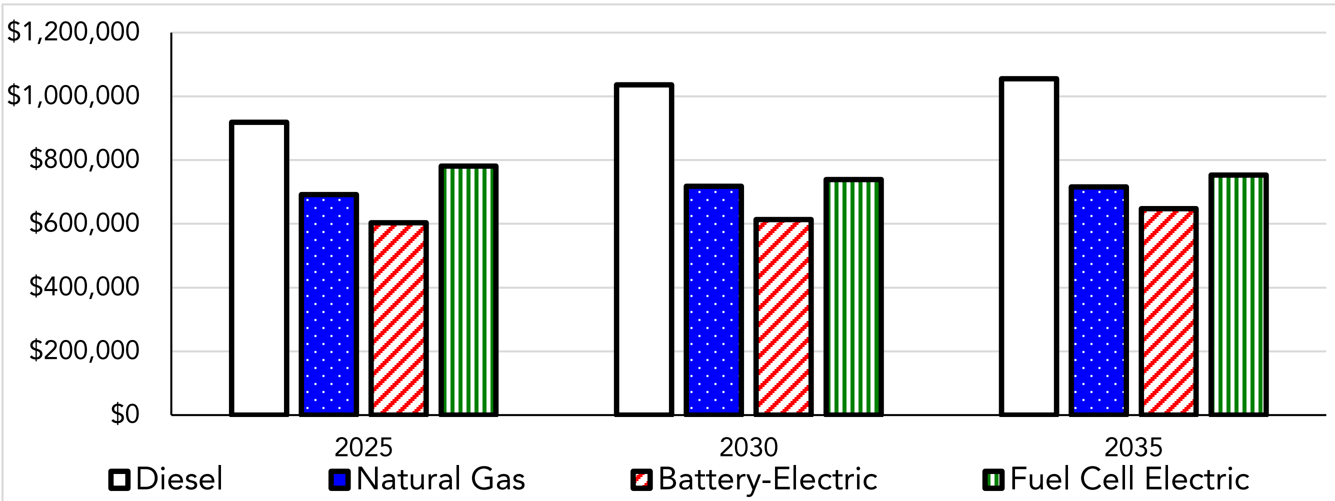


Figure 5: Day Cab Tractor TCO Comparison

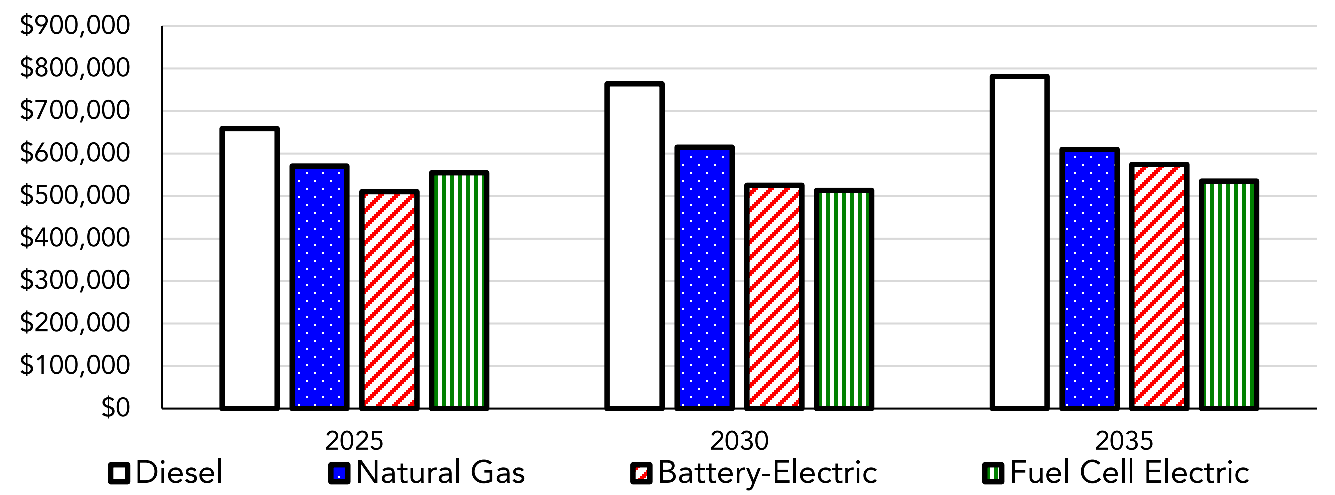
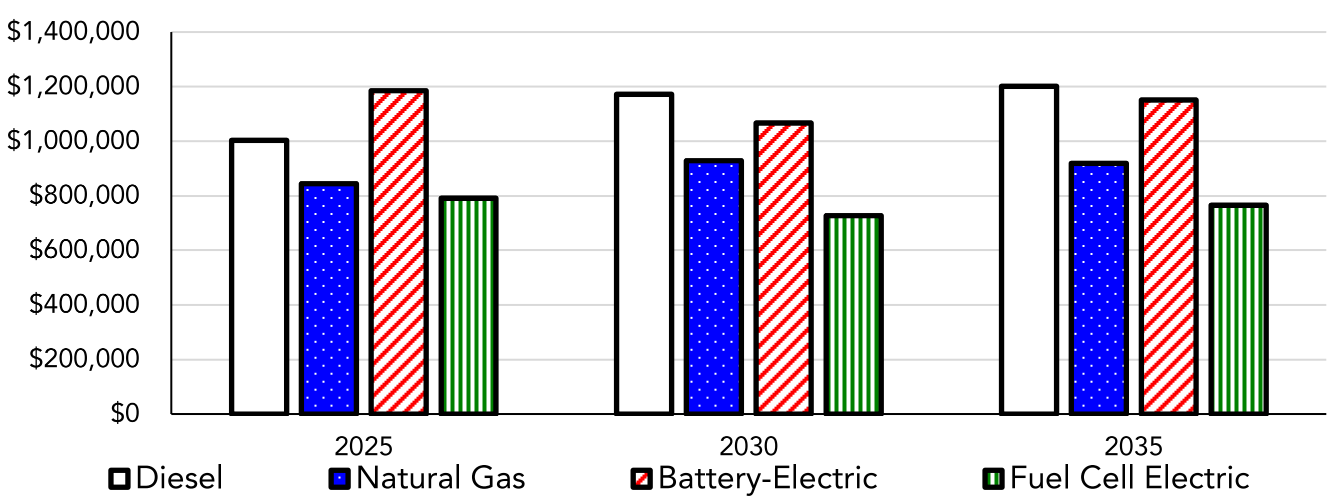


Figure 6: Sleeper Cab Tractor TCO Comparison



In addition to these TCO analysis, staff has analyzed the cashflow for vehicles over the expected operating lifetime

Figure 7: 2025 Cargo Van Cashflow Comparison

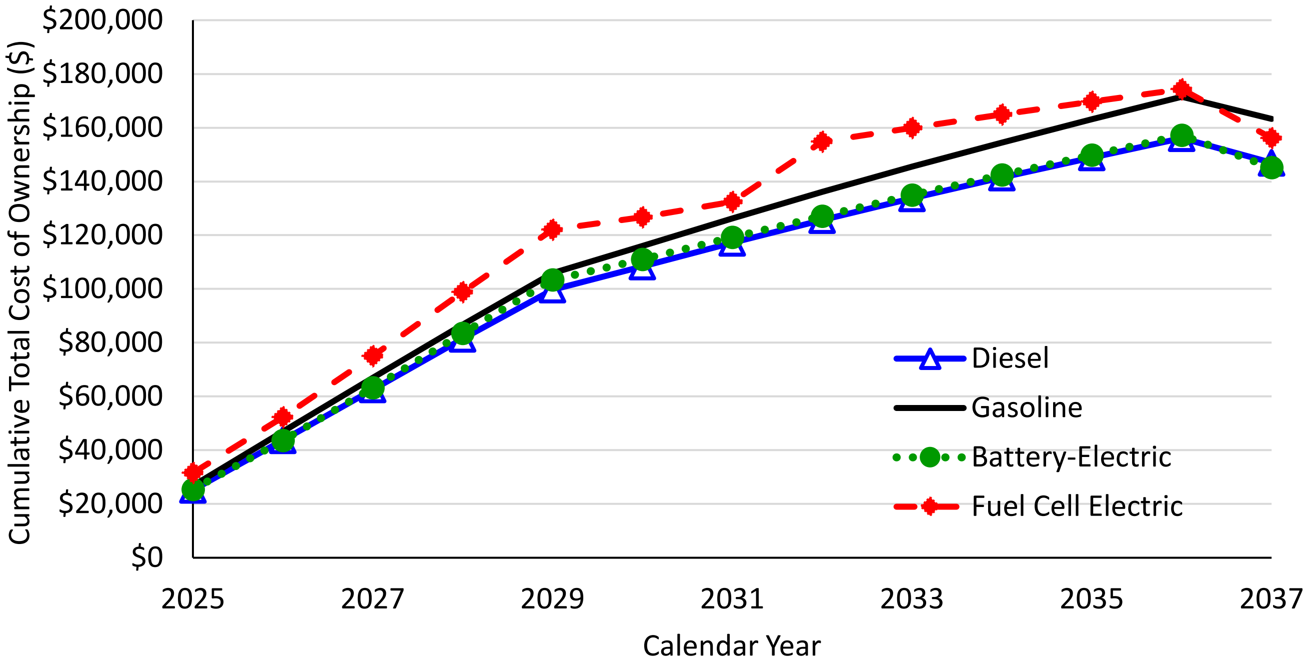
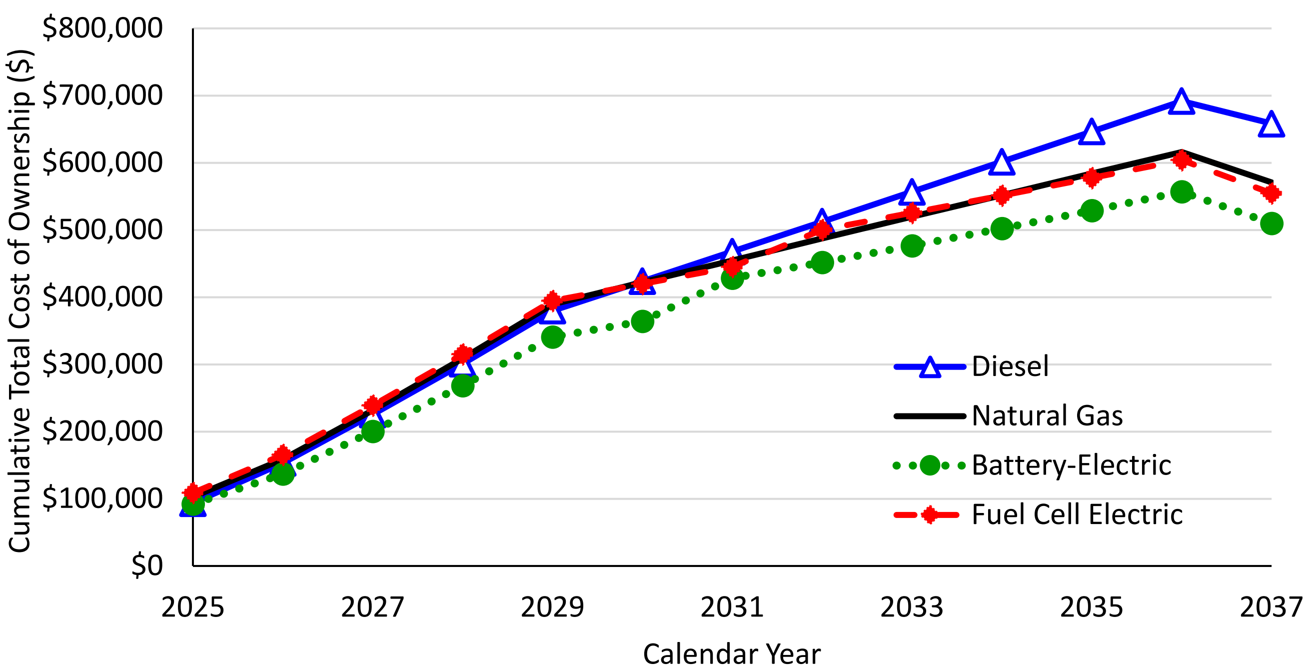


Figure 8: 2025 Day Cab Tractor Cashflow Comparison



The results of this analysis suggests the following:

- Costs of batteries and fuel cell components are expected to decline substantially over the next decade and will bring down the incremental capital costs of zero-emission trucks and buses. This will further improve their TCO compared to the combustion equivalents. Cost reductions beyond what is modeled are feasible and become more likely with large scale investment into ZEV technologies by manufacturers and fleets.
- Through a combination of lower fuel costs, decreased maintenance expenses, and revenue from California's LCFS program, ZEVs achieve lower operational costs versus their combustion counterparts. These savings typically outweigh higher upfront costs over the lifetime of the ZEV.
- Both battery-electric and fuel cell electric vehicles are projected to be cost competitive with combustion-powered vehicles over the course of this analysis. Battery-electric vehicles appear competitive in many categories beginning 2025, while fuel cell electric vehicles appear competitive in either 2025 or 2030 depending on the type of vehicle modeled.
- ZEVs can result in significantly TCO for fleets in specific scenarios. For example, by 2030, a battery-electric Class 5 walk-in van is expected to have a 22 percent lower TCO versus their diesel counterpart resulting in a savings of $47,000 per vehicle. A battery-electric and fuel cell electric day cab operating in a drayage duty cycle is expected to have a 31 and 33 percent lower TCO versus diesel, respectively, resulting in savings of $239,000 and $251,000, respectively.
- Further cost reductions may be feasible as this report does not model potentially reduced costs to fleets as a result of the Advanced Clean Fleets manufacturer ZEV sales requirement. Investments and action by manufacturers can lead to lower costs through out the entire ZEV ecosystem including parts suppliers, infrastructure providers, service technicians, and others.
- Upfront costs are expected to be higher for ZEVs due to additional vehicle and infrastructure expenses. However, by financing these costs and allowing operational savings to accrue, fleets can operate ZEVs with minimal cashflow impact in the initial years. Once the vehicle is paid off, operational savings continue to accrue over time. This allows fleets to purchase and operate ZEVs without seeing the additional costs associated with ZEVs.
- The payback period for ZEVs versus their diesel counterpart varies among vehicles but ranges from five to 10 years in the 2025 analysis. This drops to two to five years in the 2030 and 2035 analyses, indicating that ZEVs are able to recoup their additional costs in a reasonable timeframe.
- Revenue from LCFS credits significantly improves the TCO for battery-electric and fuel cell electric vehicles. LCFS credits can completely offset the cost of charging a battery-electric vehicle and significantly reduce the costs of refueling fuel cell electric vehicles.
- Although they are not included in this analysis, grants, incentives, and utility infrastructure programs can further reduce the upfront costs if fleet owners act early.

III. Introduction

Achieving California's aggressive greenhouse gas and criteria pollutant emissions goals will require large-scale deployment of ZEVs everywhere feasible in all transportation sectors. This strategy is outlined in all of CARB's planning documents such as the Sustainable Freight Action Plan, the 2020 Mobile Source Strategy, the ZEV Action Plan, the Scoping Plan, and more. The Advanced Clean Fleets regulation provides a key solution to meeting the goals of these planning documents and the emissions reductions required under the Clean Air Act by supporting the transition of California's fleets to zero-emission technologies. Advanced Clean Fleets is a component of a package of regulations to clean up California's trucks through a combination of enhanced inspection and maintenance, sales mandates through the Advanced Clean Trucks regulation, fleet phase-in requirements, incentives and recognition, and cleaner fuels and engines.

This purpose of this report is to evaluate the TCO of battery-electric and hydrogen fuel cell electric to combustion-powered technologies – diesel, gasoline, and natural gas. This report covers differences in upfront costs, operating costs, infrastructure installations, and other associated costs and savings resulting from a shift to these new technologies. This report follows analysis performed by the CARB over the prior years. In December 2020, CARB staff released the "Cost Data and Methodology Discussion Draft" to share data sources and general methodology to solicit feedback on what assumptions to make. The work performed here builds upon years of workshops, workgroups, and stakeholder analysis performed during development of the Advanced Clean Trucks regulation. This report does not quantify potential reductions in cost due to expanded medium- and heavy-duty ZEV manufacturing as a result of the Advanced Clean Trucks regulation. As a result, costs may end up lower as regulated manufacturers will need to create products that meet consumer demands at an attractive price point in order to ensure they can meet their ZEV sales obligations.

Several representative vehicles have been modeled to illustrate the TCO across a variety of vocations and weight classes: a Class 2b cargo van, a Class 5 walk-in van, a Class 6 bucket truck, a Class 8 refuse truck, a Class 8 day cab tractor in drayage operations, and a Class 8 sleeper cab tractor. This report analyzes the cost of purchasing a new vehicle as ZEVs will not be available in the secondary market for a number of years.

This report is an assessment of key cost components that differ significantly between technologies including the purchase cost of the vehicle, ongoing fueling and maintenance costs, Low Carbon Fuel Standard (LCFS) revenue, infrastructure, and other assorted vehicle operating costs. The analysis does not include any vouchers, rebates, or grants for ZEVs to show how the costs compare without subsidies. The LCFS credit is a form of incentive, but is a market-based mechanism that is part of a regulation to increase the use of low carbon transportation fuels in California. Costs that are not expected to change among vehicle types, like overhead and driver wages are not included in the TCO analysis.

This report does not evaluate catenary electric systems, dynamic charging systems, hydrogen internal combustion, or other combustion fuels. This analysis follows Department of Finance guidelines and as a result uses 2020 constant dollars and does not use discount rates. Please provide comments or suggestions on the assumptions, methodology, or any other components to the *ACF email address* (zevfleet@arb.ca.gov).

IV. Duty Cycle

How fleets operate their vehicles affects many operating characteristics and varies between fleets. In the SRIA, staff will be using EMFAC projections to model duty cycles. This includes separately modelling vehicle categories, their fuel types, and vehicle accrual rates. EMFAC also models vehicle lifetimes and the rate that trucks enter and leave the California truck population. This report presents a simplified analysis to analyze one vehicle at a time in a typical use case to allow clear comparisons rather than the entire truck population as is necessary for the SRIA.

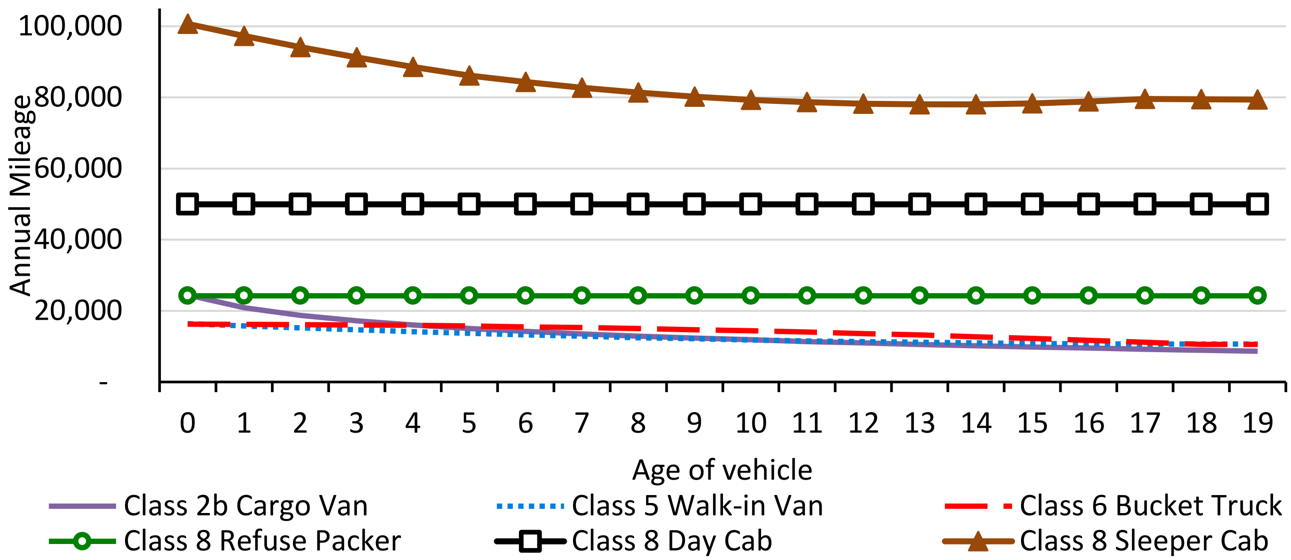
Annual Mileage

Annual mileage factors into a number of costs in this analysis including battery size, fuel costs, maintenance, and LCFS revenue. All annual mileage assumptions are based on EMFAC inventory estimates – for example day cab tractors, the T7 POLA category representing drayage trucks at the San Pedro Bay ports was used.[1,2] For most vehicle categories, annual mileage is the highest for newer vehicles and drops over time as the vehicle ages. EMFAC data was matched to the different representative vehicles. Figure 9 illustrates the accrual rates for a set of sample vehicles.

[1] California Air Resources Board, EMFAC 2021, 2021 (web link: https://arb.ca.gov/emfac/, last accessed September 2021).

[2] Eastern Research Group, *Heavy-Duty Vehicle Accrual Rates: Final Report*, 2019 (web link: https://ww2.arb.ca.gov/sites/default/files/2021-03/erg_finalreport_hdv_accruals_20190614_ada.pdf, last accessed August 2021).

Figure 9: Annual Mileage over Time for Modeled Vehicles



Staff assumes ZEVs will travel the same distance as their combustion-powered counterparts. As shown in Figure 9, the majority of single-unit trucks such as walk-in vans and refuse trucks travel under 25,000 miles per year which represents 100 miles per day. Most medium- and heavy-duty ZEVs available today can achieve this threshold and future product launches advertise higher range options. For tractors, the majority of in-state tractors travel below 200 miles per day based on sources such as CA-VIUS.[3] Manufacturers including Freightliner, Volvo, Tesla, and others have announced ZE tractor launches in 2021 and 2022 that are capable of meeting these needs. Long haul applications can be electrified through a combination of fuel cell technologies and battery-electric vehicles utilizing charging during rest breaks and in-between shifts.[4] As technology improves and publicly available infrastructure is built, staff anticipates all vehicle types will be able to perform similar duty cycles regardless of their powertrain technology.

Operating Years

Operating years indicate a reasonable representation of how long the vehicle is expected to stay in use. This discussion document assumes that a single fleet will own and operate a truck for a significant portion of its life in California. An operating life of 12 years will be used throughout this analysis to simplify the comparisons. This represents a middle ground between fleets who operate their trucks for five years before turning them over and those who operate their trucks for 20 or more years until the truck cannot operate. Most vehicles can last 20 or more years based on Department of Motor Vehicle (DMV) and EMFAC

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[3] California Department of Transportation, *CalTrans Truck Survey*, 2018 (web link: http://www.scag.ca.gov/committees/CommitteeDocLibrary/mtf012319_CAVIUS.pdf, last accessed May 2021).
[4] Lawrence Berkeley National Laboratory, *Why Regional and Long-haul Trucks are Primed for Electrification Now*, 2021 (web link: https://eta-publications.lbl.gov/sites/default/files/updated_5_final_ehdv_report_033121.pdf, last accessed August 2021).

emission inventory survival rate data. For purposes of the SRIA analysis, staff will use vehicle lifetimes as modelled by EMFAC where the overall population for a given model declines over time as vehicles leave the California fleet.

V. Vehicle Costs

Vehicle Price

This section covers the cost to the fleet of purchasing a vehicle. Today and for the foreseeable future, battery-electric and fuel cell electric trucks will cost more upfront than their combustion-powered counterparts. Declining battery and component costs in addition to economies of scale are expected to lower the incremental costs of ZEVs as the market expands.

Base gasoline and diesel new vehicle prices are based on averages of prices taken from manufacturers' websites and online truck marketplaces such as TruckPaper and Commercial Truck Trader. [5] New natural gas vehicle prices are derived from sources which estimate the incremental cost of upfitting a gasoline or diesel-powered vehicle to run on natural gas.[6,7] Table 1 displays sample new vehicle prices for a variety of applications and technology types.

Table 1: New Combustion-Powered Vehicle Prices

Vehicle	Vehicle Price
Class 2b Cargo Van – Diesel	$39,000
Class 2b Cargo Van – Gasoline	$35,000
Class 5 Walk-in Van – Diesel	$87,000
Class 5 Walk-in Van – Natural Gas	$104,500
Class 6 Bucket Truck – Diesel	$126,000
Class 8 Refuse Packer – Diesel	$226,000
Class 8 Refuse Packer – Natural Gas	$256,295
Class 8 Day Cab – Diesel	$130,000
Class 8 Day Cab – Natural Gas	$180,000
Class 8 Sleeper Cab – Diesel	$140,000
Class 8 Sleeper Cab – Natural Gas	$230,000

[5] California Air Resources Board, New Vehicle Cost Analysis, 2021.
[6] National Renewable Energy Laboratory, *VICE 2.0: Vehicle and Infrastructure Cash-Flow Evaluation Model*, 2014 (web link: https://www.afdc.energy.gov/files/u/publication/VICE_2_0_Jan_17_14.xlsx).
[7] JB Hunt, *Natural Gas in Transportation*, 2014 (web link: https://jbhcdn001.azureedge.net/files/0001723_NATURAL_GAS_WHITE_PAPER_022014.pdf).

The Federal and California Phase 2 GHG regulations require manufacturers to build trucks that have lower GHG emissions and are more fuel efficient. These requirements start in 2021 MY and ramp up through the 2027 MY. U.S. EPA estimated the cost per vehicle to comply with the regulation shown in Table 2.[8] These costs are added to the base cost of combustion-powered vehicles. Because ZEVs produce zero tailpipe emissions, they do not incur increased costs due to the Phase 2 GHG regulation.

Table 2: U.S. EPA Phase 2 GHG Estimated Incremental Compliance Costs

Phase 2 Category	2021-2023 MY	2024-2026 MY	2027+ MY
Class 2b-3 Pickup/Van	$524	$963	$1,364
Vocational Vehicles	$1,110	$2,022	$2,662
Tractors	$6,484	$10,101	$12,442

The Low-NOx Omnibus rulemaking is a multi-pronged, holistic approach to decrease emissions of new heavy-duty engines sold in California beginning in the 2024 MY. The regulation was approved by the Board but has not yet been approved by the Office of Administrative Law. The regulation would lower NOx emissions by lowering tailpipe NOx standards, establishing a new low-load test cycle to ensure emissions reductions are occurring in all modes of operation, strengthening durability, lengthening warranty and useful life, and in-use testing provisions, along with other measures. The costs to a typical fleet purchasing combustion-powered vehicles based on the certification type and the MY is shown in Table 3.

Table 3: CARB Low-NOx Omnibus Estimated Increase in Purchase Price

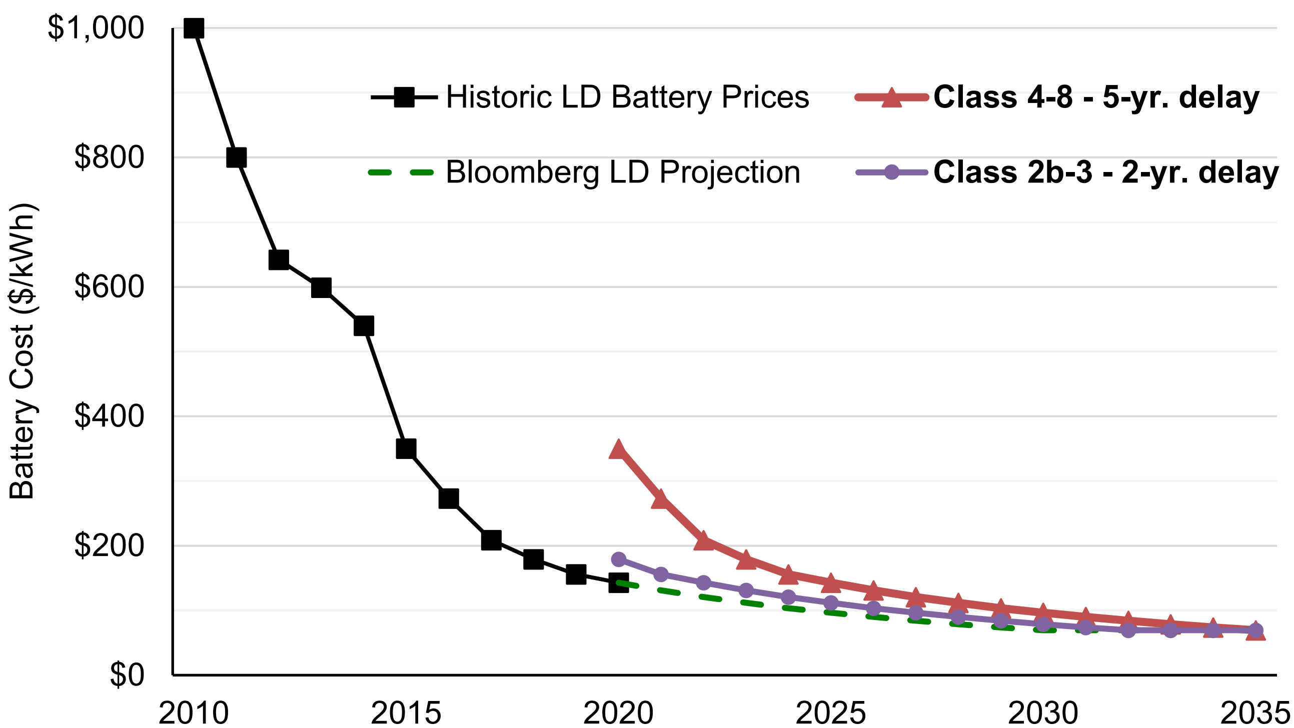
Vehicle Category	Corresponding Weight Class	2024-2026 MY	2027-2030 MY	2031+ MY
Medium-Duty Otto	Class 3	$412	$412	$412
Medium-Duty Diesel	Class 3	$1,554	$3,916	$4,354
Heavy-Duty Otto	Class 4-8	$506	$821	$1,015
Light-Heavy-Duty Diesel	Class 4-5	$1,687	$4,741	$6,041
Medium-Heavy-Duty Diesel	Class 6-7	$2,469	$6,063	$6,923
Heavy-Heavy-Duty Diesel	Class 8/Tractors	$3,761	$7,423	$8,478

Staff estimated the cost of medium- and heavy-duty ZEVs for battery-electric and fuel cell powered vehicles by adding electric components costs, fuel cell component costs, and energy storage costs to a conventional glider vehicle. The final retail price of the ZEV is the sum of the total component costs adjusted by an additional ten percent for other upfront costs such as research, development, retooling, and overhead. The calculated prices for BEVs are comparable to battery-electric trucks and vans that are available through the HVIP program today.

[8] United States Environmental Protection Agency, *Final Rule for Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles - Phase 2*, 2016 (web link: https://www.govinfo.gov/content/pkg/FR-2016-10-25/pdf/2016-21203.pdf, last accessed May 2021).

The cost of battery storage is the largest contributing factor associated with the price of BEVs. Battery pack costs have dropped nearly 90 percent since 2010 and are projected to continue declining. Battery pack cost for medium- and heavy-duty applications are higher than for light-duty cars due to smaller volumes and differing packaging requirements even though many use the same cells. At the December 4th, 2018, ACT workgroup meeting, a number of manufacturers suggested we use light-duty battery prices with a 5-year delay to reflect battery price projections that are applicable to medium- and heavy-duty vehicles. Since that time, product announcements from manufacturers have indicated that smaller trucks and vans can share components with light-duty vehicles and as a result see lower component costs. Because these vehicles still need unique engineering and are built at lower scale than light-duty vehicles, staff is assuming Class 2b-3 vehicles will follow light-duty battery prices with a 2-year delay. Staff is using Bloomberg price projections as the basis for these battery price projections. Figure 10 shows the historic battery price trend and the battery price projections used in this analysis (shown in bold).

Figure 10: Historic Battery Price Trends and Battery Price Projections



The costs for BEVs are modelled using motors and electrical components in line with an existing diesel counterpart's power needs. Battery storage is estimated using the vehicle's average daily mileage based on EMFAC data and the energy efficiency of the electric vehicle in 2020. For vehicles which EMFAC models as driving below 100 miles per day, staff assumed the battery would have a minimum capability of driving 100 miles daily. Staff then modeled an additional 35 percent buffer to account for battery degradation and some operational variability. Table 4 lists the battery size specifications.

Table 4: Battery Size Calculation

Representative Vehicle	Daily Mileage	2020 Efficiency (kWh/mi)	Battery Size (kWh)
Class 2b Cargo Van	100	0.6	80
Class 5 Walk-in Van	100	1	135
Class 6 Bucket Truck	100	1.5	205
Class 8 Refuse Packer	100	3.0	405
Class 8 Day Cab	160	2.1	455
Class 8 Sleeper Cab	320	2.1	1,050

The hydrogen fuel cell vehicles are modeled using a 10 kWh battery and a fuel cell stack whose power output is half the vehicle's peak power needs. Hydrogen storage varies based on the vehicle: Class 2b-3 vehicles have 10 kg of storage, Class 4-6 vehicles have 20 kg of storage, Class 7-8 vehicles have 40 kg of storage, and Class 8 sleeper cab tractors have 80 kg of storage.

Generally, heavy-duty vehicles are manufactured in stages. A chassis manufacturer such as Ford or Freightliner installs a powertrain built by themselves or an outside supplier to produce a cab-and-chassis. This is then sent to a body manufacturer to install a body on the vehicle such as a box or bucket truck body. These body costs are modeled separately for ZEVs. The cost of a body can be estimated by measuring the difference between the price of a cab-and-chassis and the finished vehicle with a body. For this analysis, staff assumes bodies requiring power takeoff – in this case the bucket truck and refuse truck – will cost 10 percent extra up until 2030 to account for additional costs of electrifying the power takeoff. No increased costs are modeled for bodies without power takeoff.

The assumed vehicle prices for vehicles of all fuel types are shown in Table 5.

Table 5: New Vehicle Price Forecast

Vehicle	2025 MY	2030 MY	2035 MY
Class 2b Cargo Van – Diesel	$39,963	$40,364	$40,364
Class 2b Cargo Van – Gasoline	$35,963	$36,364	$36,364
Class 2b Cargo Van – Battery-Electric	$52,447	$48,001	$47,174
Class 2b Cargo Van – Fuel Cell Electric	$79,405	$67,592	$67,489
Class 5 Walk-in Van – Diesel	$90,709	$94,403	$95,703
Class 5 Walk-in Van – Natural Gas	$107,028	$107,983	$108,177
Class 5 Walk-in Van – Battery-Electric	$113,571	$105,167	$105,167
Class 5 Walk-in Van – Fuel Cell Electric	$129,422	$119,397	$119,397
Class 6 Bucket Truck – Diesel	$130,491	$134,725	$135,585
Class 6 Bucket Truck – Battery-Electric	$156,349	$144,073	$139,903
Class 6 Bucket Truck – Fuel Cell Electric	$176,695	$161,317	$157,147
Class 8 Refuse Packer – Diesel	$231,783	$236,085	$237,140
Class 8 Refuse Packer – Natural Gas	$258,823	$259,778	$259,972
Class 8 Refuse Packer – Battery-Electric	$299,932	$276,029	$266,929
Class 8 Refuse Packer – Fuel Cell Electric	$316,578	$294,380	$285,280
Class 8 Day Cab – Diesel	$143,862	$149,865	$150,920
Class 8 Day Cab – Natural Gas	$195,607	$198,263	$198,457
Class 8 Day Cab – Battery-Electric	$201,999	$176,028	$176,028
Class 8 Day Cab – Fuel Cell Electric	$212,353	$190,155	$190,155
Class 8 Sleeper Cab – Diesel	$153,862	$159,865	$160,920
Class 8 Sleeper Cab – Natural Gas	$240,607	$243,263	$243,457
Class 8 Sleeper Cab – Battery-Electric	$304,629	$247,638	$247,638
Class 8 Sleeper Cab – Fuel Cell Electric	$251,403	$226,272	$226,272

Taxes

Taxes are additional costs levied on the purchase of a vehicle. Because they are based on the purchase price of the vehicle, they are higher for ZEVs due to their higher upfront costs.

Vehicles purchased in California must pay a sales tax on top of the vehicle's purchase price. The sales tax varies across the state from a minimum of 7.25 percent up to 10.25 percent in some municipalities where 3.94 percent goes towards the State and the remaining portion goes towards local governments. A value of 8.5 percent was used for the sales tax rate based on a statewide population-weighted average.

Class 8 vehicles are subject to an additional federal excise tax which adds 12 percent to their purchase price.

Financing

For the purpose of this analysis, vehicle purchases are assumed to be financed over a five-year period. Staff assumes most fleets will be able to finance at a lower interest rate while some less creditworthy fleets will have to finance for higher rates. To reflect this, staff modeled that 80 percent of fleets will finance at a 5 percent annual percentage rate and 20 percent of fleets will finance at 15 percent, resulting in an average financing rate of 7 percent.

VI. Operating Costs

Operating costs are how many miles a vehicle drives annually and the per mile costs of the vehicle.

Fuel Cost

Fuel costs are calculated using total fuel used per year and the cost of fuel per unit. In general, ZEVs are 2 to 5 times as efficient as similar vehicles with ICE technologies, they significantly reduce petroleum and other fossil fuel consumption, and they use less total energy.

Gasoline and diesel fuel prices to 2030 are taken from the California Energy Commission's (CEC) "Fuel Price Forecasts" and are adjusted to 2021 dollars using the California consumer price index (CPI).[9] The "High Electricity Growth" scenario was used given the anticipated increase in electricity use due to this regulation and other upcoming CARB regulations. Gasoline and diesel fuel prices to 2030 are taken from CEC's "Fuel Price Forecasts" and adjusted to 2021 dollars using California consumer price index (CPI). [10] The annual percentage change in the U.S. Energy Information Administration (EIA) fuel prices past 2030 is applied to the 2030 CEC gasoline and diesel prices to estimate price changes past 2030. Figure 11 shows the projected prices of gasoline, diesel, and natural gas out to 2050.

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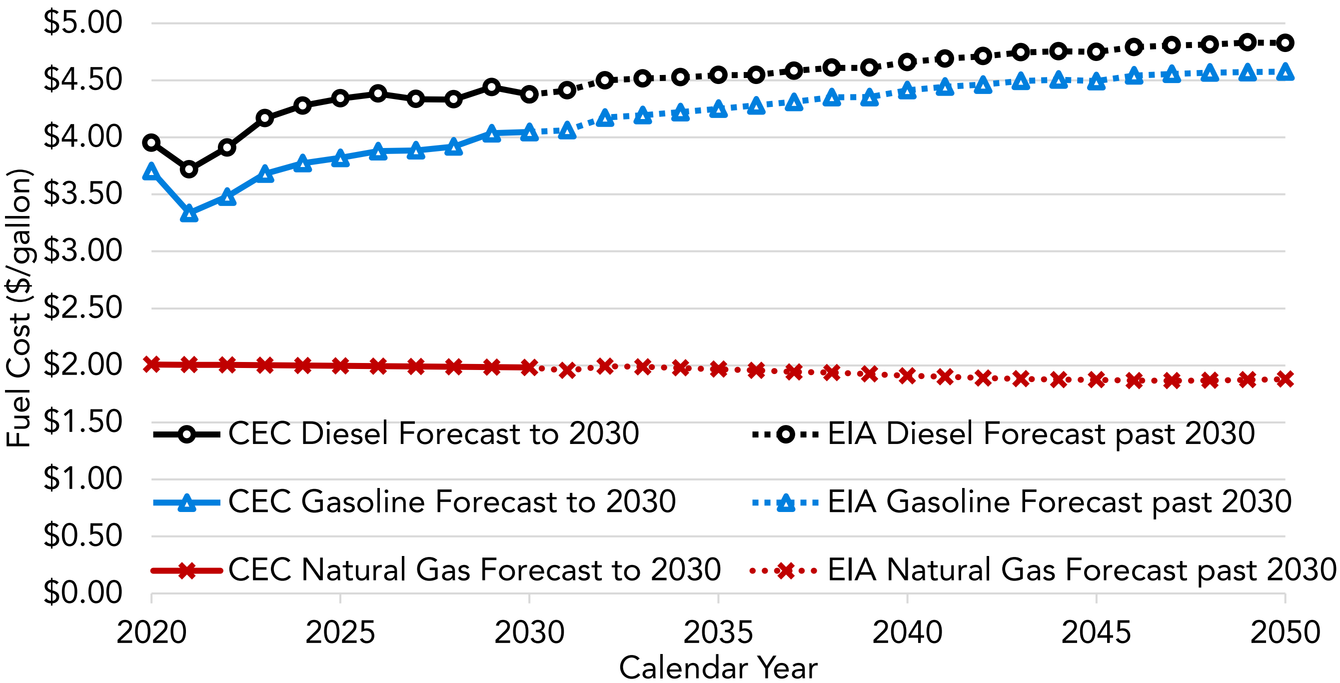
[9] California Energy Commission, *Revised Transportation Energy Demand Forecast 2018-2030*, 2017 (web link: https://efiling.energy.ca.gov/getdocument.aspx?tn=235841, last accessed May 2021).

[10] California Energy Commission, *Revised Transportation Energy Demand Forecast 2018-2030*, 2017 (web link: https://efiling.energy.ca.gov/getdocument.aspx?tn=235841, last accessed May 2021).

Figure 11: Gasoline, Diesel, and Natural Gas Price Forecasts



Electricity costs for battery-electric vehicles depend on the rate and on how they are charged, and include energy costs, fixed fees, and demand fees. Vehicles charged at high power or during peak periods will have higher electricity costs than if charging overnight or over an extended period. For this analysis, staff assumes most BEVs will primarily utilize depot charging while Class 8 sleeper cab tractors will primarily rely on retail charging.

Electricity prices for depot charging are calculated using CARB's Battery-Electric Truck and Bus Charging Calculator and assumes a fleet of 20 vehicles using a managed charging strategy with the applicable rate schedule.[11] Day cab tractors are assumed to be charged in a four-hour shift at night along with opportunity midday charging sessions at the depot. All other trucks are assumed to charge overnight. Charger efficiency losses and local electricity taxes are incorporated into these numbers. The cost per kWh is calculated separately for each utility and a weighted average is used to determine the cost per kWh per vehicle in 2021. Table 6 shows the depot charging electricity price per kWh for each vehicle and major utility region as well as the weighted statewide average which was used in this report. In general, electricity costs are lower for larger vehicles because they tend to use more electricity which decreases the fixed costs per kWh and allows the use of lower cost rate schedules for larger utility customers. Note that Southern California Edison's (SCE) newly introduced electric vehicle rates, EV-8 and EV-9, have no demand fees from 2019 to 2023; these fees will phase back in over the following five years, with demand fees being fully reintroduced in 2029. However, to simplify the analysis, staff used the full cost of the SCE electricity rate including all demand charges from the beginning of the analysis period rather than discounting the price to reflect the transition period until the demand charges are fully reintroduced.[12]

Table 6: Electricity Cost Calculation for 2021

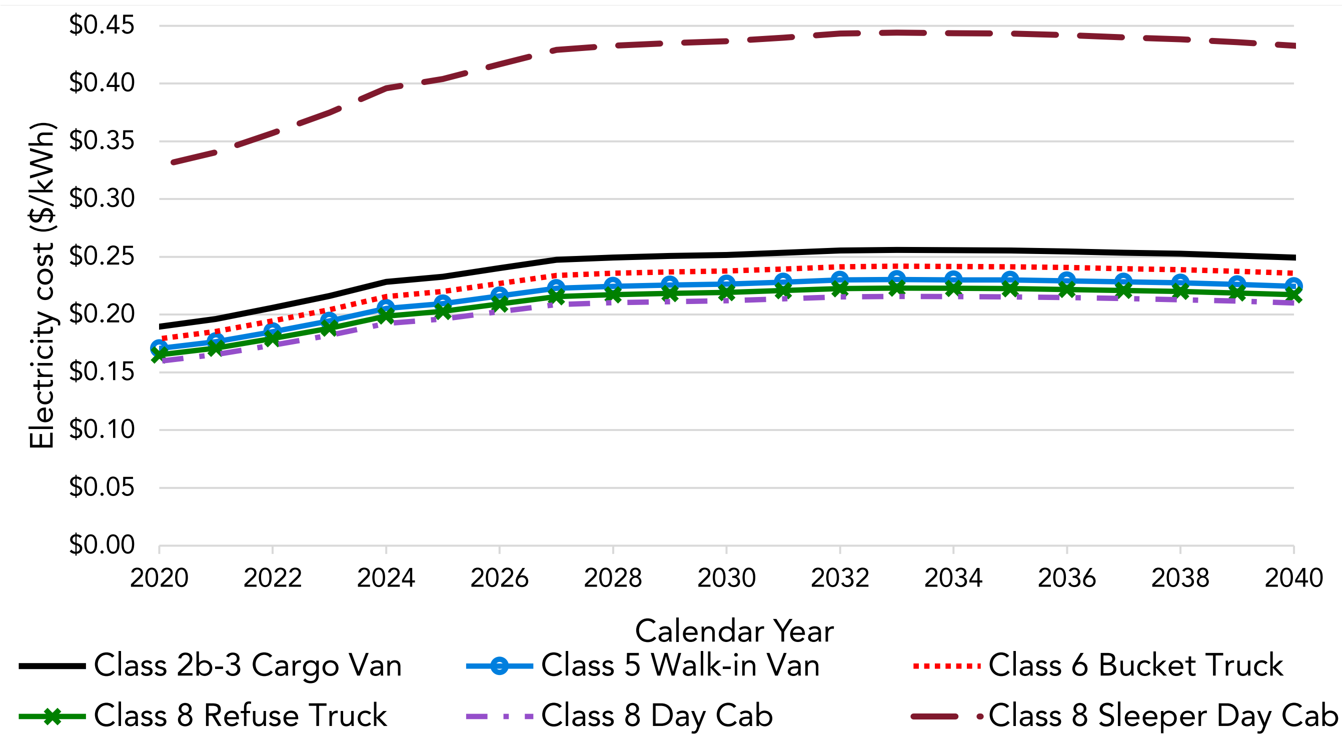
Utility Area	Cargo Van	Walk-in Van	Bucket Truck	Refuse Truck	Day Cab Tractor
Los Angeles Department of Water and Power	$0.11	$0.11	$0.13	$0.11	$0.17
Pacific Gas and Electric (PG&E)	$0.15	$0.15	$0.16	$0.15	$0.14
Sacramento Municipal Utility District	$0.17	$0.16	$0.16	$0.14	$0.14
San Diego Gas and Electric (SDG&E)	$0.21	$0.20	$0.22	$0.20	$0.15
Southern California Edison (SCE)*	$0.19	$0.15	$0.15	$0.14	$0.15
Weighted Statewide Average	$0.18	$0.16	$0.17	$0.16	$0.16

Sleeper cab tractors are assumed to require a retail charging network instead of utilizing depot charging. For retail charging, staff assumes the price for medium- and heavy-duty retail charging would be similar to current direct current fast charging costs for light-duty at $0.31/kWh.[13] This electricity cost includes all costs associated with building the publicly accessible station and its infrastructure.

[11] California Air Resources Board, *Battery-Electric Truck and Bus Charging Calculator*, 2021 (web link: https://ww2.arb.ca.gov/resources/documents/battery-electric-truck-and-bus-charging-cost-calculator, last accessed May 2021).
[12] Southern California Edison, Communication via email with Alexander Echele in April 2019.
[13] Electrify America, *Pricing and Plans for EV Charging*, 2021 (web link: https://www.electrifyamerica.com/pricing/, last accessed May 2021).

Electricity price changes over time are modeled using CEC's "Revised Transportation Energy Demand Forecast, 2018-2030", adjusted to 2018 dollars using California CPI. Fuel prices after 2030 are calculated using the EIA 2018 Annual Energy Outlook for the Pacific region. The annual percentage changes in EIA gasoline and diesel fuel prices after 2030 are applied to the 2030 CEC gasoline and diesel prices to estimate future price changes. Results by vehicle type are shown in Figure 12.

Figure 12: Electricity Price Forecasts



For this analysis, hydrogen stations were assumed to be available at strategic locations around seaports or major distribution hubs where the infrastructure costs are included in the hydrogen fuel price rather than reflecting costs for stations installed in a depot. This model is currently used for light-duty hydrogen stations and medium- and heavy-duty diesel sales and is based on stakeholder feedback; it appears to be most appropriate for medium- and heavy-duty hydrogen fueling. Hydrogen fuel costs are based on values provided by "Road Map to a U.S. Hydrogen Economy," a report released by a coalition of major hydrogen stakeholders including automotive, fuel cell, petroleum, and power companies.[14] Hydrogen costs over time are shown in Figure 13.

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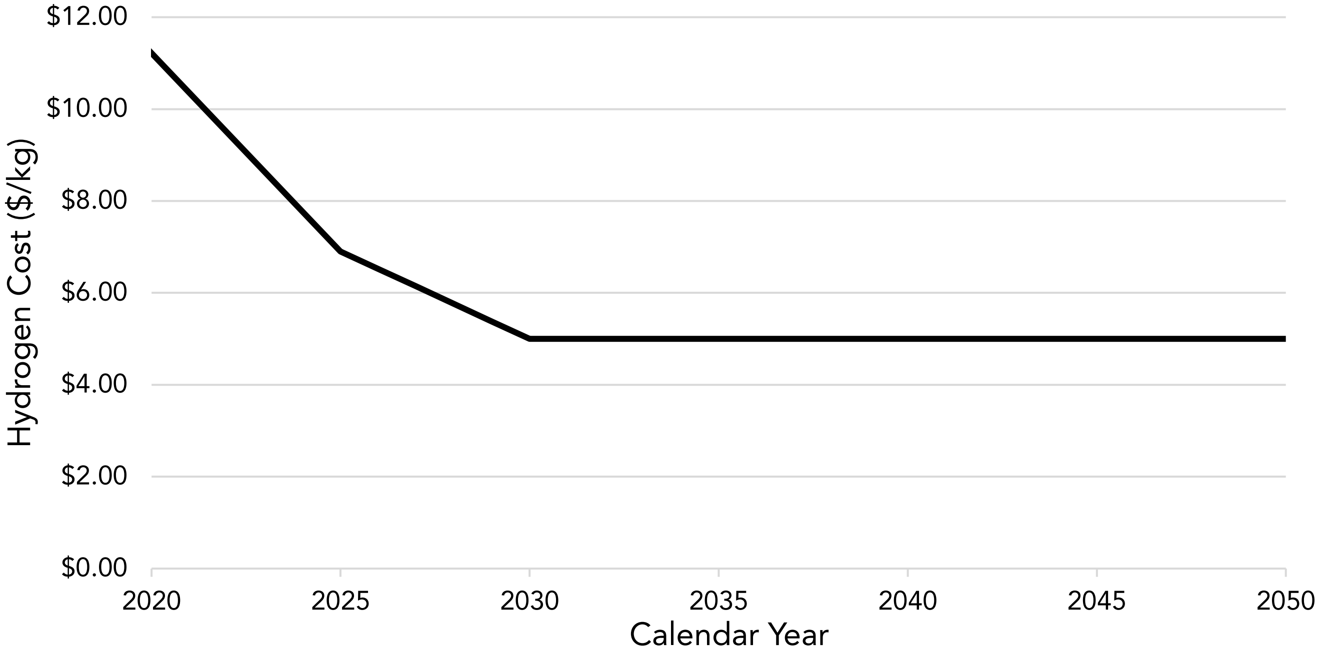
[14] Fuel Cell & Hydrogen Energy Association, *"Road Map to a US Hydrogen Economy,"* (https://www.fchea.org/us-hydrogen-study, last accessed May 2021)

Figure 13: Hydrogen Price Forecasts



Fuel economy is measured in miles per gallon for gasoline and diesel, miles per kWh for battery-electric, and miles per kg for fuel cell electric trucks. Gasoline, diesel, and natural gas fuel economy is derived from EMFAC inventory projections for each group. These projections incorporate the effects of the Phase 2 GHG regulation.

BEV fuel economy is derived from in-use data collected from a variety of vehicles and estimates made from similar vehicles.[15,16,17] For fuel cell efficiency, staff applied the LCFS program's Energy Efficiency Ratios (EER) of 2.5 and 1.9 for Class 2b-3 and Class 4-8 vehicles, respectively, to the diesel fuel economy to estimate the fuel cell fuel economy as there is limited information which measures the fuel efficiency of medium- and heavy-duty FCEVs. Sleeper cab ZEV fuel economy is estimated to be 15 percent higher than the equivalent day cab tractor ZEV fuel economy values based on the relative difference between Phase 2 GHG standards for the two classes of vehicles.

Staff's modeling assumes that for both BEVs and FCEVs, the efficiency will improve at the same rate as the Phase 2 GHG regulation would require for combustion-powered vehicles until 2027 MY, then remain constant afterwards. This may be a conservative estimate as both technologies are less developed than ICE powertrains and reports have shown improvements in the technology recently.

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[15] California Air Resources Board, *Battery Electric Truck and Bus Efficiency Compared to Diesel Vehicles* (web link: https://ww2.arb.ca.gov/sites/default/files/2018-11/180124hdbevefficiency.pdf, last accessed May 2021).
[16] Penn State LTI Bus Research and Testing Center, *Motor Coach Industries D45 CRTeLE*, 2020 (web link: http://apps.altoonabustest.psu.edu/buses/reports/522.pdf?1608733416, last accessed May 2021).
[17] Penn State LTI Bus Research and Testing Center, *GreenPower Motor Company EV Star*, 2020 (web link: http://apps.altoonabustest.psu.edu/buses/reports/515.pdf?1603821665, last accessed May 2021).

Table 7 outlines the fuel economy assumptions for the modeled vehicles over the modeled time period.

Table 7: Vehicle Fuel Economy Data

Vehicle	2025 MY	2030 MY	2035 MY	Unit
Class 2b Cargo Van – Gasoline	18.96	15.25	15.24	mpg
Class 2b Cargo Van – Diesel	13.78	11.73	11.73	mpg
Class 2b Cargo Van – Battery-Electric	1.89	2.00	2.00	mi./kWh
Class 2b Cargo Van – Fuel Cell Electric	44.60	47.24	47.24	mi./kg
Class 5 Walk-in Van – Diesel	9.10	8.05	8.33	mpg
Class 5 Walk-in Van – Natural Gas	7.62	6.53	6.56	mpdge
Class 5 Walk-in Van – Battery-Electric	1.13	1.20	1.20	mi./kWh
Class 5 Walk-in Van – Fuel Cell Electric	16.06	17.01	17.01	mi./kg
Class 6 Bucket Truck – Diesel	8.58	7.58	7.84	mpg
Class 6 Bucket Truck – Battery-Electric	0.76	0.80	0.80	mi./kWh
Class 6 Bucket Truck – Fuel Cell Electric	15.05	15.94	15.94	mi./kg
Class 8 Refuse Packer – Diesel	3.06	2.48	2.61	mpg
Class 8 Refuse Packer – Natural Gas	6.27	4.83	4.88	mpdge
Class 8 Refuse Packer – Battery-Electric	0.38	0.40	0.40	mi./kWh
Class 8 Refuse Packer – Fuel Cell Electric	5.20	5.51	5.51	mi./kg
Class 8 Day Cab – Diesel	6.75	5.55	5.30	mpg
Class 8 Day Cab – Natural Gas	6.54	5.25	5.01	mpdge
Class 8 Day Cab – Battery-Electric	0.54	0.57	0.57	mi./kWh
Class 8 Day Cab – Fuel Cell Electric	10.93	11.58	11.58	mi./kg
Class 8 Sleeper Cab – Diesel	6.94	5.75	5.47	mpg
Class 8 Sleeper Cab – Natural Gas	6.32	4.99	4.69	mpdge
Class 8 Sleeper Cab – Battery-Electric	0.47	0.50	0.50	mi./kWh
Class 8 Sleeper Cab – Fuel Cell Electric	10.98	11.63	11.63	mi./kg

Diesel Exhaust Fluid Consumption

Diesel-powered vehicles equipped with modern emissions control devices require diesel exhaust fluid (DEF) to break down NOx in the exhaust stream. Argonne National Laboratory estimates DEF consumption as being 2 percent of total fuel usage in their online 2020 AFLEET tool.[18] This assumption will be applied to the fuel economy discussed previously to estimate the DEF consumption per mile. DEF is assumed to cost $2.80 per gallon per Argonne.

Low Carbon Fuel Standard Revenue

The LCFS is a California regulation that creates a market mechanism that incentivizes low carbon fuels. The regulation requires the carbon intensity of California's transportation fuels

[18] Argonne National Laboratory, *Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool*. (https://greet.es.anl.gov/afleet, last accessed May 2021)

to decrease by 20 percent through the 2030 timeframe and maintains the standard afterwards. Fleets using electricity and hydrogen are eligible to earn LCFS credits which can be sold to offset the costs of these fuels. Fossil gasoline and diesel are not eligible for LCFS credits.

Fleets that own and operate their infrastructure generate credits based on the amount of fuel or energy they dispense. The amount of revenue generated by LCFS credits depends on the credit price. For this analysis, staff is projecting an LCFS credit price of $200 until 2030, then declining linearly to $25 in 2045 and remaining constant thereafter. The amount of revenue generated for different fuel types is calculated using the LCFS Credit Price Calculator.[19] In 2025, an electric Class 2b-3 vehicle will earn $0.147/kWh using grid electricity while an electric Class 4-8 vehicle will earn roughly $0.249/kWh at this credit price. Staff assumes hydrogen is produced from 33 percent renewable feedstock as required by SB 1505 (2006). This results in Class 2b-3 vehicles earning $3.034/kg and Class 4-8 vehicles earning $1.839/kg in 2025. LCFS credit revenue for a given fuel drops slightly over time as the program standards tighten and maintains upward pressure on the credit price.

For retail electricity refueling for sleeper cab tractors, staff conservatively assumes that retail refueling stations will not pass-through any LCFS credit revenue until 2030 due to limited competition and low utilization of early retail charging stations. Starting 2031, staff assumes ZEV charging station operators will pass-through LCFS credit revenue to fleets in order to remain competitive with other operators.

This analysis reflects that the LCFS value associated with natural gas is already included in the retail price to the fleet owner. Fossil natural gas is expected to be a deficit generator in the LCFS program for the majority of this analysis and will not generate revenue. While renewable natural gas does generate LCFS credits, the credits are typically claimed by the fuel producer and are used to offset the higher cost of renewable natural gas. Therefore, the net cost to the fleet owner using renewable natural gas is essentially the same as fossil-based natural gas.

Maintenance Costs

Maintenance costs reflect the cost of labor and parts for routine maintenance, preventative maintenance, and repairing broken components but do not include costs reflected in the next section "Midlife Costs" where engine rebuilds, battery replacements, or fuel cell stack refurbishments are described. Maintenance costs for electric vehicles are generally assumed to be lower than for diesel vehicles, in part due to their simpler design and fewer moving components.

[19] California Air Resources Board, *LCFS Credit Price Calculator*, 2021(web link: https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/dashboard/creditvaluecalculator.xlsx, last accessed May 2021).

Maintenance costs for combustion-powered vehicles are based on numerous published studies assessing maintenance costs for vehicles over a representative timeframe.[20, 21, 22, 23, 24, 25, 26] The maintenance cost for the selected representative vehicles was calculated by identifying all sources where the maintenance cost appeared for the representative vehicles and averaging the values. Maintenance costs for different combustion technologies are assumed to be the same due to a lack of data on the differences between technologies.

ZEVs are assumed to have 25 percent lower vehicle maintenance costs compared to gasoline and diesel, based on an aggregation of sources and data.[27, 28, 29, 30] While numerous reports assume ZEVs can achieve maintenance costs of 50 percent or greater, the lack of long-term data on maintenance costs presents uncertainty for modeling purposes; therefore, the staff analysis uses the lower estimate.

Table 8 illustrates the maintenance costs for the modeled vehicles.

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[20] Argonne National Laboratory, *AFLEET Tool*, 2020 (web link: https://greet.es.anl.gov/afleet_tool, last accessed May 2021).
[21] National Renewable Energy Laboratory, *FedEx Express Gasoline Hybrid Electric Delivery Truck Evaluation: 12-Month Report*, 2011 (web link: https://www.nrel.gov/docs/fy11osti/48896.pdf, last accessed May 2021).
[22] National Renewable Energy Laboratory, *Thirty-Six Month Evaluation of UPS Diesel Hybrid-Electric Delivery Vans*, 2012 (web link: https://www.nrel.gov/docs/fy12osti/53503.pdf, last accessed May 2021).
[23] National Renewable Energy Laboratory, *Eighteen-Month Final Evaluation of UPS Second Generation Diesel Hybrid-Electric Delivery Vans*, 2012 (web link: https://www.nrel.gov/docs/fy12osti/55658.pdf, last accessed May 2021).
[24] Bloomberg, *What Tesla's Big Rig Must Do to Seduce Truckers*, 2017 (web link: https://www.bloomberg.com/news/articles/2017-11-15/what-tesla-s-semi-truck-must-do-to-seduce-truckers, last accessed May 2021)
[25] American Truck Research Institute, *An Analysis of the Operational Costs of Trucking: 2018 Update*, 2018. (web link: https://truckingresearch.org/wp-content/uploads/2018/10/ATRI-Operational-Costs-of-Trucking-2018.pdf, last accessed May 2021).
[26] Fleet Advantage, *Mitigating Rising M&R Costs for Class-8 Truck Fleets*, 2018 (web link: http://info.fleetadvantage.com/mitigating-rising-fleet-maintenance-and-repair-costs-for-class-8-trucks, last accessed May 2021).
[27] California Air Resources Board, *Literature Review on Transit Bus Maintenance Cost* (web link: https://www.arb.ca.gov/regact/2018/ict2018/appg.pdfhttps://www.arb.ca.gov/msprog/bus/maintenance_cost.pdf, last accessed May 2021)
[28] Electrification Coalition, *State of the Plug-in Electric Vehicle Market* (web link: https://www.pwc.com/gx/en/automotive/industry-publications-and-thought-leadership/assets/pwc-ec-state-of-pev-market-final.pdf, last accessed May 2021)
[29] Propfe, B. et.al. *Cost analysis of Plug-in Hybrid Electric Vehicles including Maintenance & Repair Costs and Resale Values* (web link: http://www.mdpi.com/2032-6653/5/4/886, last accessed May 2021)
[30] Taefi, T. et.al. *Comparative Analysis of European examples of Freight Electric Vehicle Schemes*, (web link: http://nrl.northumbria.ac.uk/15185/1/Bremen_final_paperShoter.pdf, last accessed May 2021)

Table 8: Vehicle Maintenance Costs per Mile

Vehicle	Maintenance Cost ($/mi.)
Class 2b Cargo Van – Diesel	$0.337
Class 2b Cargo Van – Gasoline	$0.337
Class 2b Cargo Van – Battery-Electric	$0.253
Class 2b Cargo Van – Fuel Cell Electric	$0.253
Class 5 Walk-in Van – Diesel	$0.210
Class 5 Walk-in Van – Natural Gas	$0.210
Class 5 Walk-in Van – Battery-Electric	$0.158
Class 5 Walk-in Van – Fuel Cell Electric	$0.158
Class 6 Bucket Truck – Diesel	$0.700
Class 6 Bucket Truck – Battery-Electric	$0.525
Class 6 Bucket Truck – Fuel Cell Electric	$0.525
Class 8 Refuse Packer – Diesel	$0.943
Class 8 Refuse Packer – Natural Gas	$0.943
Class 8 Refuse Packer – Battery-Electric	$0.708
Class 8 Refuse Packer – Fuel Cell Electric	$0.708
Class 8 Day Cab – Diesel	$0.198
Class 8 Day Cab – Natural Gas	$0.198
Class 8 Day Cab – Battery-Electric	$0.149
Class 8 Day Cab – Fuel Cell Electric	$0.149
Class 8 Sleeper Cab – Diesel	$0.159
Class 8 Sleeper Cab – Natural Gas	$0.159
Class 8 Sleeper Cab – Battery-Electric	$0.119
Class 8 Sleeper Cab – Fuel Cell Electric	$0.119

Midlife Costs

Midlife costs are the cost of rebuilding or replacing major propulsion components due to wear or deterioration. These costs do not include general maintenance on vehicles – these are included in the "Maintenance Costs" section. The frequency and cost of a midlife rebuild across varies across the different technologies. For combustion-powered vehicles, this would be a midlife rebuild, for BEVs this would be a battery replacement, and for a hydrogen FCEV this would be a fuel cell stack refurbishment.

Combustion-powered vehicles are expected to need a midlife rebuild at the end of their engine's useful life. The useful life periods were determined in the Low-NOx Omnibus rulemaking based on the vehicle's weight class and are displayed in Table 9. [31] Once the vehicle's engine reaches the end of its useful life, the vehicle will require an engine rebuild. The cost of this rebuild is estimated at 25 percent of the total vehicle price minus body costs.

Table 9: Useful Life of Diesel Engines

Vehicle/Engine Category	Useful Life (Years/Miles)
Class 4-5 (Light-Heavy-Duty)	15/270,000
Class 6-7 (Medium-Heavy-Duty)	12/350,000
Class 8 (Heavy-Heavy-Duty)	12/800,000

BEVs are expected to need battery replacements as battery's health degrades over time. Long-term battery performance is limited for heavy-duty BEVs today, but today's ZEV manufacturers are offering vehicles with warranties of eight or more years and up to 300,000 miles on their products. [32,33,34] Staff anticipates battery durability will continue to improve as manufacturers strive to meet fleet needs. Based on this, staff estimates that the battery will be replaced every 300,000 miles prior to 2030 and every 500,000 miles afterwards. The cost of the battery replacement is assumed to be the size of the battery in kWh multiplied by the price per kWh at the time of the replacement.

For FCEVs, the consulting firm Ricardo has estimated that a fuel cell stack refurbishment is necessary every seven years and costs one third the cost of a new fuel cell stack at the time of refurbishment.[35]

To provide an example, the midlife costs of a 2025 MY day cab tractor of four different fuel types would be:

- Diesel and natural gas: The tractor engine will need to be overhauled after 12 years in 2037 the overhaul is expected to cost $35,966
- Battery-electric: The vehicle is expected to reach 300,000 miles after 7 years and the battery replacements in 2031 is expected to cost $31,275
- Fuel cell electric: A fuel cell stack refurbishments would occur after 7 years in 2031at a cost of $9,917 for the refurbishment

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[31] California Air Resources Board, *Public Hearing to Consider the Proposed Heavy-Duty Engine And Vehicle Omnibus Regulation and Associated Regulatory Amendments – Staff Report: Initial Statement of Reasons*, 2020 (web link: https://ww2.arb.ca.gov/sites/default/files/classic/regact/2020/hdomnibuslownox/isor.pdf, last accessed May 2021).
[32] BYD, *The BYD K9*, 2019 (web link: https://en.byd.com/wp-content/uploads/2019/07/4504-byd-transit-cut-sheets_k9-40_lr.pdf, last accessed May 2021)
[33] New Flyer, *Xcelsior Charge*, 2019 (web link: https://www.newflyer.com/site-content/uploads/2019/06/Xcelsior-CHARGE-web.pdf, last accessed May 2021)
[34] Proterra, *Catalyst: 40 Foot Bus – Performance Specifications*, 2019 (web link: https://mk0proterra6iwx7rkkj.kinstacdn.com/wp-content/uploads/2019/06/Proterra-Catalyst-40-ft-Spec-Sheet.pdf, last accessed May 2021)
[35] Ricardo, Economics of Truck TCO and Hydrogen Refueling Stations, 2016

Registration Fees

Vehicles operating and registered in California must pay an annual registration fee. The registration fee varies based on the vehicle's cost, age, and weight. These calculations are different for combustion-powered vehicles and ZEVs.

Combustion-powered vehicles and ZEVs are subject to the following fixed fees based on the DMV online calculator.[36] These are constant annual fees for every vehicle and are shown in Table 10 and Table 11.

Table 10: Fixed Registration Fees for ICE Vehicles

Diesel Fee Name	Amount
Current Registration	$61
CVRA Registration Fee	$122
CVRA Service Authority for Freeway Emergencies Fee	$3
CVRA Fingerprint ID Fee	$3
CVRA Abandoned Vehicle Fee	$3
CVRA California Highway Patrol Fee	$46
Current Air Quality Management District	$6
Current Cargo Theft Interdiction Program Fee	$3
CVRA Weight Decal Fee	$3
Alt Fuel/Tech Registration Fee	$3
CVRA Auto Theft Deterrence/DUI Fee	$4
Reflectorized License Plate Fee	$1
Total	$258

Table 11: Fixed Registration Fees for ZEVs

ZEV Fee Name	Amount
Current Registration	$61
Current California Highway Patrol	$28
CVRA Service Authority for Freeway Emergencies Fee	$1
CVRA Fingerprint ID Fee	$1
CVRA Abandoned Vehicle Fee	$1
Current Air Quality Management District	$6
Alt Fuel/Tech Registration Fee	$3
CVRA Auto Theft Deterrence/DUI Fee	$2
Reflectorized License Plate Fee	$1
Road Improvement Fee	$100
Total	$204

[36] California Department of Motor Vehicles, *California New Vehicle Fees*, 2021 (web link: https://www.dmv.ca.gov/portal/dmv/detail/portal/feecalculatorweb, last accessed May 2021).

All vehicles registered in California must pay a Transportation Improvement Fee based on the price of the vehicle. As of 2021, the fee is $171 for vehicles priced between $35,000 and $60,000, and $192 for vehicles priced above $60,000.

All registered vehicles are assessed a Vehicle License Fee which is equal to the vehicle price multiplied by 0.65 percent and a separate percentage schedule. This separate schedule is shown in Table 12.

Table 12: Vehicle License Fees Decline over Time

Year	1	2	3	4	5	6	7	8	9	10	11+
Percentage	100%	90%	80%	70%	60%	50%	40%	30%	25%	20%	15%

For commercial ICE vehicles, vehicle owners are assessed an annual weight fee based on the vehicle's potential maximum loaded weight. For electric vehicles, the weight fee is based on its unladen weight. The estimated weight fees are shown in Table 13.

Table 13: Weight Fees for ICE Vehicles and ZEVs

Weight Class	Diesel Weight Fee	ZEV Weight Fee
Class 2b-3	$210	$266
Class 4-5	$447	$358
Class 6-7	$546	$358
Class 8	$1,270	$358
Class 7-8 Tractor	$2,064	$358

Overall, a ZEV requires lower registration fees over the vehicle's life although it may be higher in the initial years of registration. This difference is greater for heavier vehicles due to the large difference in annual weight fees.

VII. Infrastructure

Infrastructure is necessary to refuel or recharge vehicles. All vehicles need either dedicated refueling infrastructure onsite or publicly available retail stations in order to operate. There are numerous ways infrastructure expenses can be accounted for which will affect the cost to California businesses in different ways. Infrastructure expenses are generally an upfront capital investment needed prior to vehicles being deployed, but infrastructure can last multiple vehicle lifetimes and generally is amortized over its life.

In this report, staff assumes gasoline, diesel, and hydrogen vehicles are either using existing infrastructure or publicly accessible stations and as a result have no separate infrastructure costs. Battery-electric and natural gas vehicle deployments will generally require the fleet making infrastructure upgrades to support their vehicles.

Natural Gas Vehicle Infrastructure

Natural gas infrastructure costs are derived from two sources. For Class 8 refuse packers and Class 8 tractors, infrastructure costs are assumed to be $40,000 per vehicle. This is based on the value used in the Innovative Clean Transit rulemaking of a 100 bus CNG refueling station costing $4,000,000.[37] For Class 4-7 vehicles, a cost value of $18,000 per vehicle is used. This was calculated using NREL's VICE 2.0 CNG model in a scenario where a fleet deploys 150 CNG delivery trucks with an average vehicle lifetime of 15 years.[38]

Battery-Electric Vehicle Infrastructure

All vehicles in this analysis other than the Class 8 sleeper cab are assumed to use depot charging. Fleets utilizing depot charging for their battery-electric vehicles will need to install chargers to recharge the vehicles as well as perform upgrades to the site to support the increased level of electricity demand. Charger costs are derived from the International Council on Clean Transportation working paper, "Estimating Electric Vehicle Charging Infrastructure Costs Across Major U.S. Metropolitan Areas".[39] Generally, smaller trucks can use Level 2 chargers similar to what light-duty vehicles use. Class 6 and heavier vehicles are assumed to require higher power direct current chargers. Class 8 single-unit vehicles are assumed to have two vehicles share a 150 kW charger while each Class 8 day cab will have its own charger.

Infrastructure upgrade costs represent costs on the customer side of the meter associated with setting up charging infrastructure at a facility and include trenching, cabling, laying conduit, potential transformer upgrades, and more. Infrastructure costs are derived from an analysis of BEV deployments conducted by CARB. The data was analyzed to calculate the cost per port and then results were broken into three groups: below 50 kW, between 50 and 250 kW, and above 250 kW. The results are shown in Figure 14 in a box-and-whisker plot.

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[37] California Air Resources Board, *Appendix K: Transit Fleet Cost Model*, 2017 (web link: https://www.arb.ca.gov/regact/2018/ict2018/appk-transitfleetcostmodel.xlsx, last accessed July 2021).
[38] National Renewable Energy Laboratory, *VICE 2.0: Vehicle Infrastructure and Cash-Flow Evaluation Model*, 2014 (web link: https://afdc.energy.gov/files/u/publication/VICE_2_0_Jan_17_14.xlsx, last accessed July 2021).
[39] International Council on Clean Transportation, *Estimating Electric Vehicle Charging Infrastructure Costs Across Major U.S. Metropolitan Areas*, 2019. (web link: https://theicct.org/sites/default/files/publications/ICCT_EV_Charging_Cost_20190813.pdf, last accessed May 2021).

Figure 14: Infrastructure Upgrade Cost per Charger Port and Power level

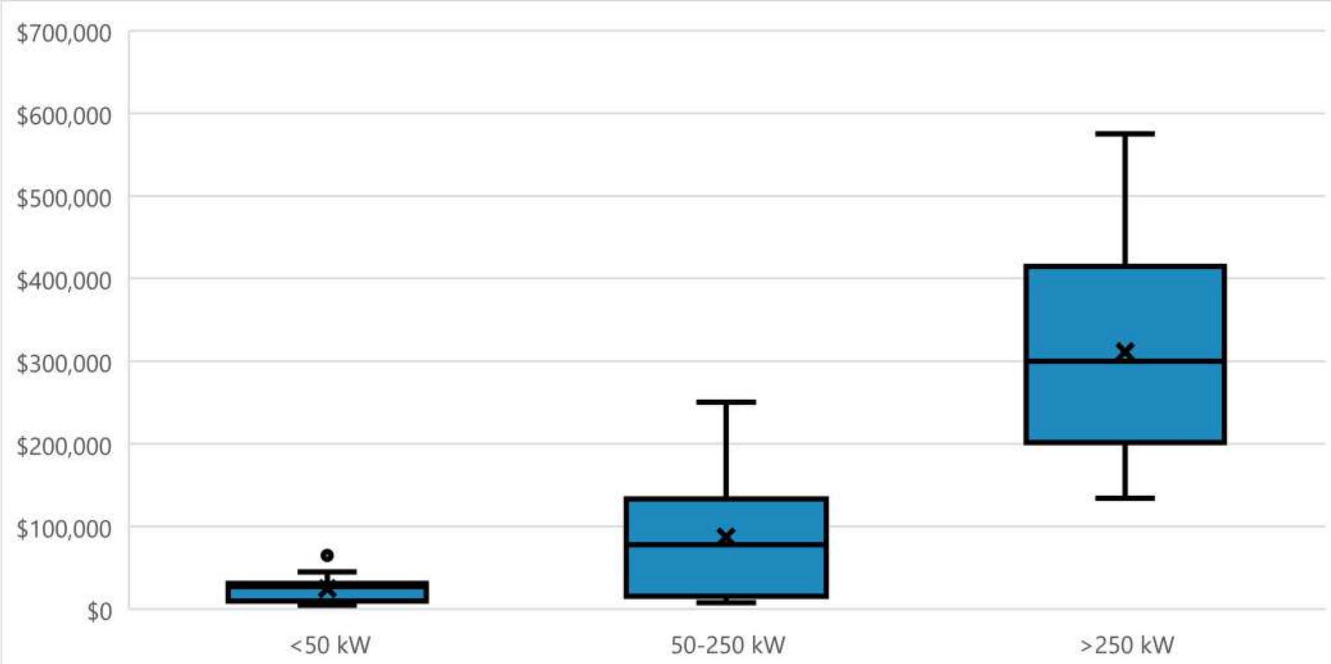


Table 14 outlines the assumptions for charger power, charger cost, and infrastructure upgrade costs. Because sleeper cab tractors are assumed to use publicly accessible retail charging, no infrastructure costs are modelled.

Table 14: Charger Power Ratings and Infrastructure Costs Per Vehicle

Vehicle	Charger Power (kW)	Charger Cost	Infrastructure Upgrade Cost
Class 2b Cargo Van	19	$5,000	$25,000
Class 5 Walk-in Van	19	$5,000	$25,000
Class 6 Bucket Truck	50	$25,000	$44,000
Class 8 Refuse Packer	150 kW for 2 vehicles	$37,500	$44,000
Class 7-8 Day Cab Tractor	150 kW	$75,000	$88,000

Fleets are assumed to amortize their infrastructure costs over a 20 year period with an interest rate of seven percent.

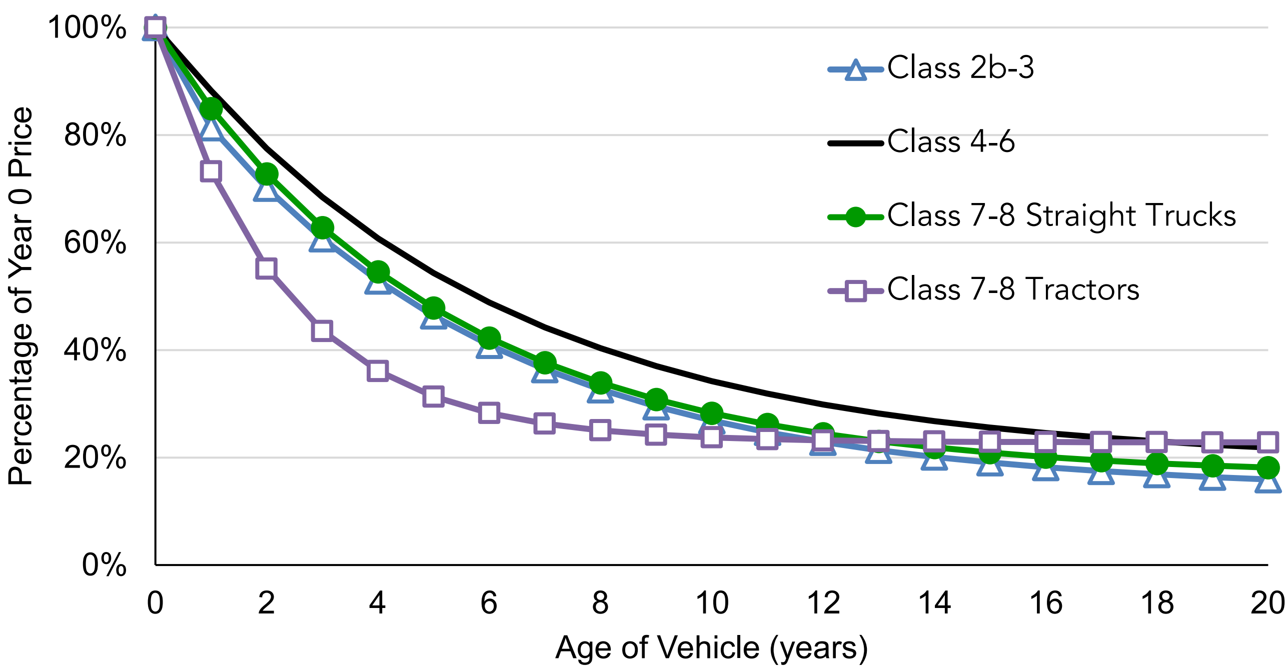
VIII. Other Assorted Costs

Residual Values

The residual value represents the value of the vehicle at the point where the initial purchaser sells the vehicle to another party. This value depends on numerous factors including the type of vehicle, its age, and the vehicle's propulsion technology and it becomes more significant when modeling vehicle replacement cycles that are less than 12 years.

The used vehicle prices for combustion-powered trucks are calculated using online truck marketplaces such as TruckPaper by measuring the price of a given body type over several body types, MYs, and weight classes. The trend is calculated by grouping similar trucks, performing a weighted average, then calculating an exponential curve fit for the different groups. Figure 15 displays the four residual value curves calculated for combustion-powered vehicles over a 20-year period.

Figure 15: Residual Values over Time by Weight Class



ZEVs are assumed to depreciate at the same rate as diesel powered vehicles.

Insurance

Fleets purchase insurance policies to protect against financial loss and a variety of unexpected events including damaging other property, damage to the vehicle, medical coverage in the event of an accident, and others. Because ZEVs are anticipated to cost more than their combustion-powered counterparts, vehicle coverage is anticipated to be more costly as well. Currently, this analysis only reflects the physical damage component of insurance costs because that is the only aspect of insurance we expect to change.

Table 15 shows the estimated cost of various insurance coverage components based on several sources staff identified. [40,41,42]

Table 15: Estimated Annual Semi Truck Insurance Policy Costs

Types of Insurance Coverage	Policy Cost
Primary Liability	$6,000
General Liability	$550
Umbrella Policy	$600
Physical Damage	$2,000
Bobtail Insurance	$375
Uninsured/Underinsured Motorist	$75
Occupational Accident	$1,900

Physical damage is the only coverage element that depends on the cost of the vehicle being operated. The other coverage types are not dependent on the cost of the vehicle. For example, if truck were to crash into a signpost, the cost of the truck would not affect the cost of paying to replace the signpost.

Based on the data shown, the "Physical Damage" coverage costs 1/70th of the price of a new semi truck; for the purpose of this analysis, staff assumes the "Physical Damage" insurance cost is proportional to 1/70th the cost of the vehicle when new. Insurance costs for a vehicle decline over time as the value of the vehicle decreases. Staff assumes the insurance costs decline at the same rate as shown in the "Residual Values" section.

Depreciation

Depreciation represents an asset's loss in value over time. This loss can be claimed as an expense and used to decrease a business's tax burden. Vehicles owned and used by businesses can have their depreciation quantified using values provided by the Internal Revenue Service (IRS) Publication 946 regarding property depreciation which may be recovered when itemizing deductions from taxes. [43] These deductions are referred to as the Modified Accelerated Cost Recovery System (MACRS) and are considered to be cost-savings.

The cost-savings from depreciation can be calculated by multiplying the vehicle's purchase price by the MACRS depreciation rate and the corporate tax rate. Per the IRS publication, most trucks follow a 5-year depreciation schedule while tractors follow a 3-year deprecation schedule. The amount of deprecation year-over-year is shown in Table 16.

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[40] Forerunner Insurance Group, *What does Average semi truck insurance costs for owner operators?*, 2018 (web link: https://www.forerunnerinsurance.com/what-does-average-semi-truck-insurance-costs-for-owner-operators/, last accessed May 2021).

[41] Commercial Truck Insurance HQ, *Average Semi Truck Insurance Cost*, 2019 (web link: https://www.commercialtruckinsurancehq.com/average-semi-truck-insurance-cost, last accessed May 2021).

[42] Strong Tie Insurance, *Why You Need a Commercial Semi Truck Insurance Coverage*, 2021 (web link: https://www.strongtieinsurance.com/semi-truck-insurance/, last accessed May 2021).

[43] Internal Revenue Service, *Publication 946 (2020), How To Depreciate Property*, 2020 (web link: https://www.irs.gov/pub/irs-pdf/p946.pdf, last accessed May 2021).

Table 16: Depreciation Rate by Age

Age	0	1	2	3	4	5	6+
Truck	20.00%	32.00%	19.20%	11.52%	11.52%	5.76%	0%
Tractor	33.33%	44.45%	14.81%	7.41%	0%	0%	0%

The vehicle value depreciated per year is multiplied by the corporate tax rate to determine the amount of tax savings per year. The California corporate tax rate is 8.84 percent and the federal corporate tax rate is 21 percent.[44,45]

IX. Total Cost of Ownership Analysis

Based on the inputs listed above, the total cost of ownership is calculated for each vehicle. The following TCO elements have been lumped together in the below graphs:

- Vehicle Costs
    - Vehicle Price
    - Taxes
    - Financing
- Net fuel costs
    - The cost of the fuel
    - DEF consumption
    - LCFS credit revenue
- Infrastructure
- Other costs, including
    - Maintenance costs
    - Midlife costs
    - Registration fees
    - Residual values
    - Insurance
    - Depreciation

All TCO analyses are performed in 2025, 2030, and 2035 except for the Class 8 sleeper cab tractor. Sleeper cab tractors do not face a requirement in the current Advanced Clean Fleets proposal until 2030 so no 2025 analysis is included.

The cumulative TCO over time has been plotted for the different fuel types to illustrate how the fleet's cashflow may differ. The simple payback period for each year and vehicle has been calculated between the ZEV and diesel models. This is done by dividing the ZEV's additional upfront vehicle and infrastructure costs by the difference in operating costs including fuel costs, LCFS revenue, maintenance, and average midlife costs.

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[44] Franchise Tax Board, *Business Tax Rates*, 2021 (web link: https://www.ftb.ca.gov/file/business/tax-rates.html, last accessed May 2021).

[45] Internal Revenue Service, *Publication 542, Corporation*, 2021 (web link: https://www.irs.gov/publications/p542, last accessed May 2021).

2025 Cargo Van

Figure 16: 2025 Cargo Van Total Cost of Ownership Comparison

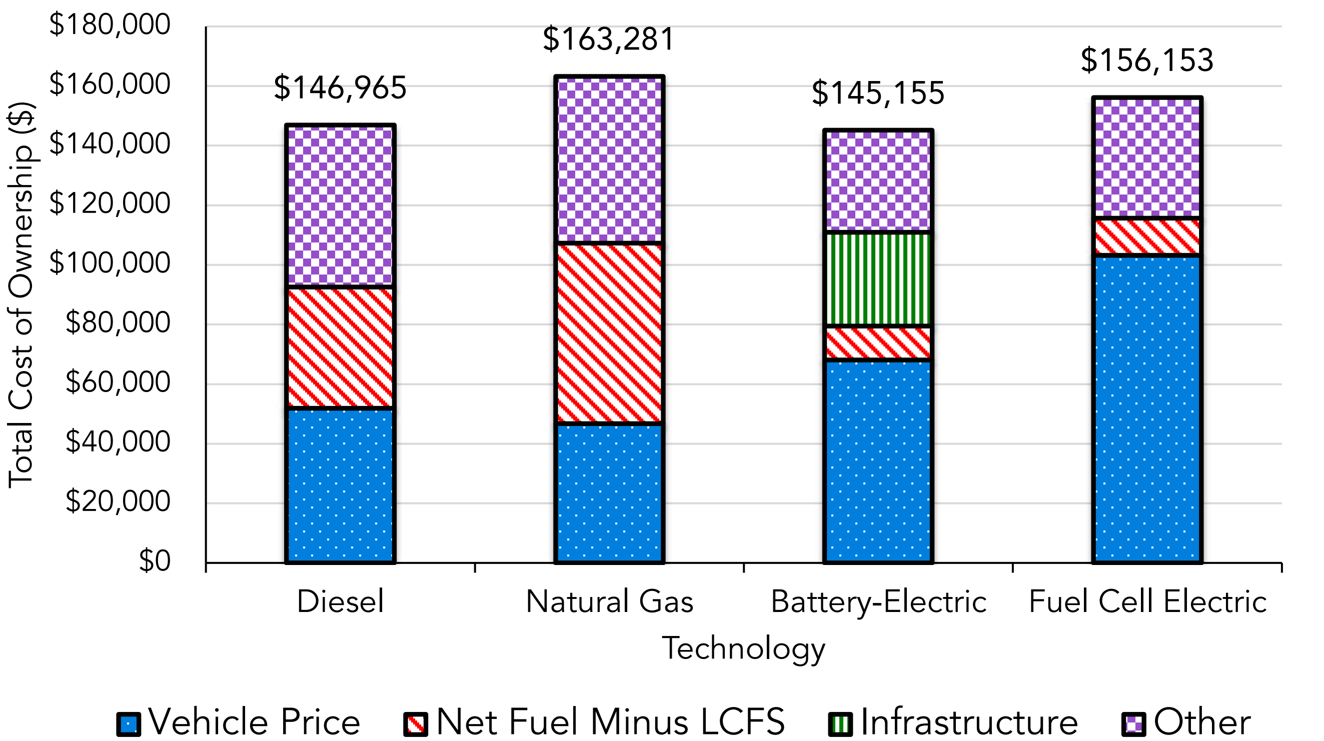

Figure 17: 2025 Cargo Van Cashflow Comparison

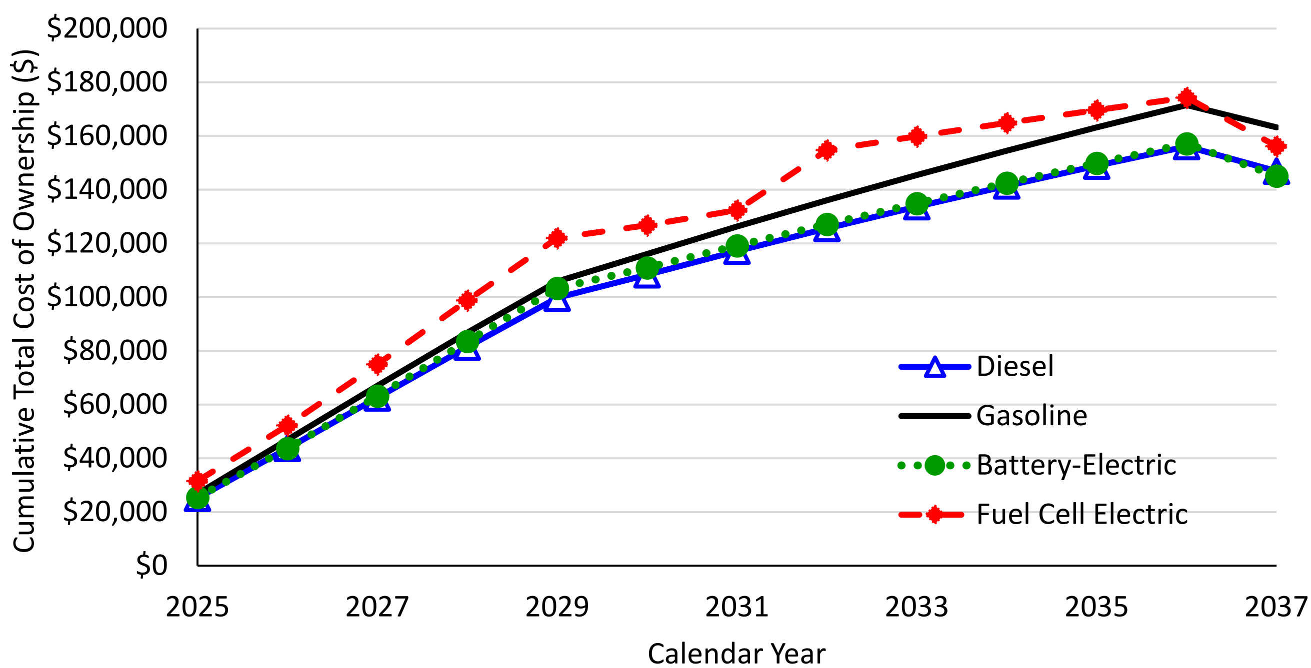

Table 17: 2025 Cargo Van Cost Breakdown

	Diesel	Gasoline	Battery-Electric	Fuel Cell Electric
Total Miles	188,600	188,600	188,600	188,600
Operating Years	12	12	12	12
Energy Storage	-	-	80 kWh	10 kWh/10 kg H2
Vehicle Power	-	-	200 kW	200 kW/100 kWFC
Vehicle Price	$39,963	$35,963	$52,447	$79,405
Taxes	$3,197	$2,877	$4,196	$6,352
Financing Costs	$8,770	$7,892	$11,510	$17,426
Total Vehicle Cost	$51,930	$46,732	$68,152	$103,183
Fuel Economy	19 mpg	13.8 mpg	1.89 mi./kWh	44.6 mi./kg
Unit Fuel Cost	$4.03/gal	$4.42/gal	$0.25/kWh	$5.63/kg
Fuel Cost	$40,068	$60,522	$24,838	$23,801
DEF Consumption	$557	$0	$0	$0
LCFS Revenue	$0	$0	-$13,495	-$11,361
Total Fuel Cost	$40,625	$60,522	$11,342	$12,440
Maintenance Cost	$63,563	$63,563	$47,672	$47,672
Midlife Costs	$0	$0	$0	$17,000
Registration Fee	$8,542	$8,387	$9,720	$11,015
Depreciation	-$11,989	-$10,789	-$15,734	-$23,821
Residual Value	-$9,145	-$8,230	-$12,002	-$18,171
Insurance Costs	$3,440	$3,096	$4,515	$6,835
Total Other Costs	$54,410	$56,027	$34,171	$40,530
EVSE Cost	$0	$0	$3,172	$0
Infrastructure Upgrade Cost	$0	$0	$28,318	$0
Total Infrastructure Cost	$0	$0	$31,489	$0
TOTAL	$146,965	$163,281	$145,155	$156,153
Payback Period vs Diesel (yr)	-	-	8.0	10.4

2030 Cargo Van

Figure 18: 2030 Cargo Van Total Cost of Ownership Comparison

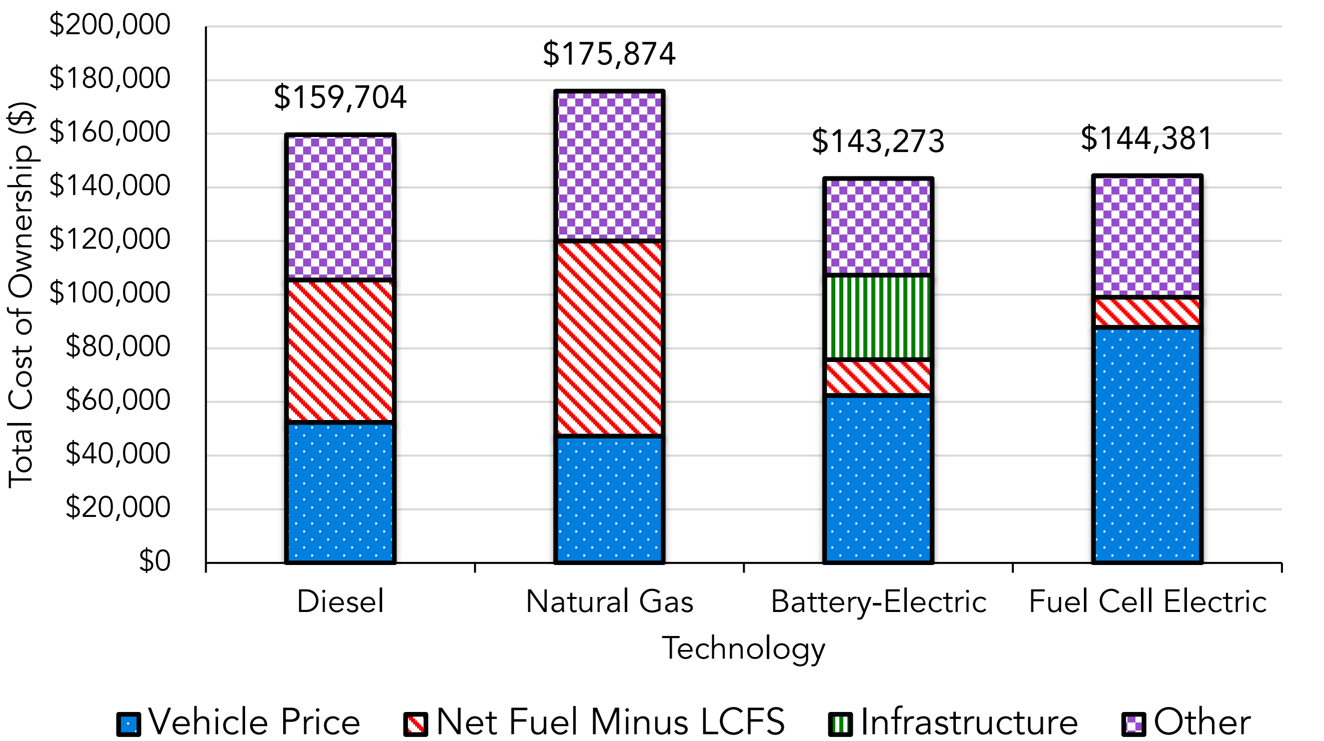

Figure 19: 2030 Cargo Van Cashflow Comparison

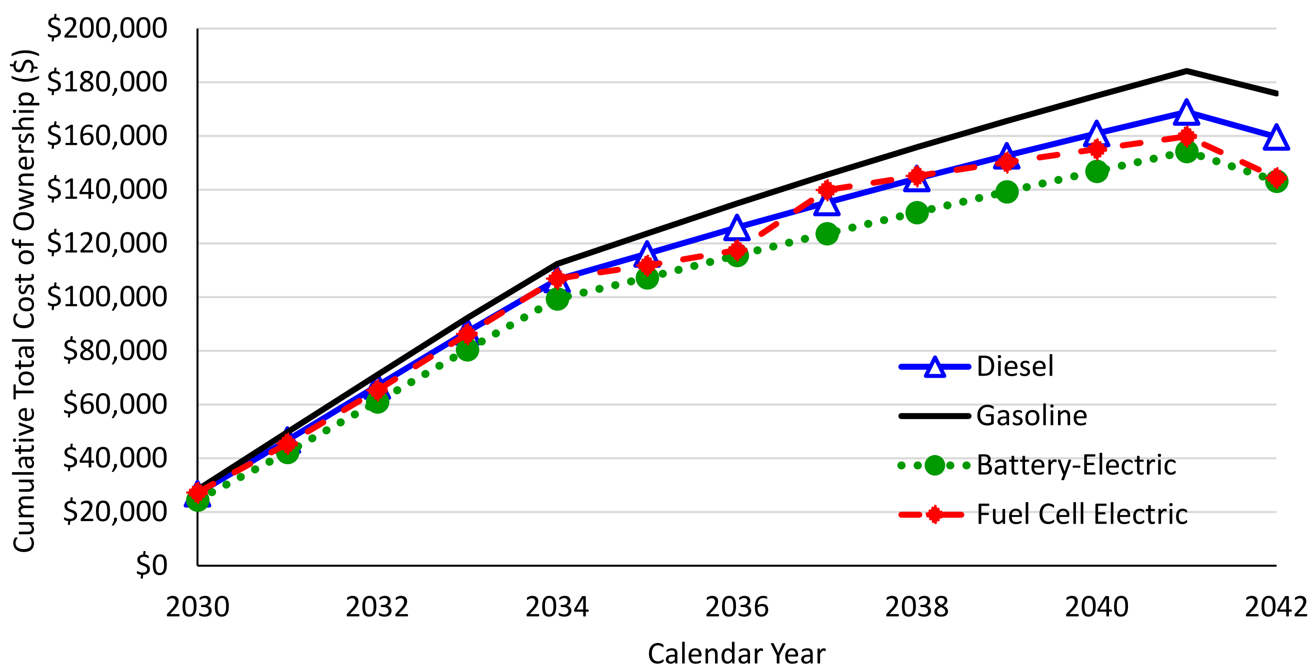

Table 18: 2030 Cargo Van Cost Breakdown

	Diesel	Gasoline	Battery-Electric	Fuel Cell Electric
Total Miles	188,600	188,600	188,600	188,600
Operating Years	12	12	12	12
Energy Storage	-	-	80 kWh	10 kWh/10 kg H2
Vehicle Power	-	-	200 kW	200 kW/100 kWFC
Vehicle Price	$40,364	$36,364	$48,001	$67,592
Taxes	$3,229	$2,909	$3,840	$5,407
Financing Costs	$8,858	$7,980	$10,534	$14,833
Total Vehicle Cost	$52,451	$47,253	$62,375	$87,833
Fuel Economy	15.3 mpg	11.7 mpg	2 mi./kWh	47.2 mi./kg
Unit Fuel Cost	$4.23/gal	$4.53/gal	$0.25/kWh	$5/kg
Fuel Cost	$52,312	$72,756	$23,889	$19,961
DEF Consumption	$693	$0	$0	$0
LCFS Revenue	$0	$0	-$10,448	-$8,717
Total Fuel Cost	$53,005	$72,756	$13,441	$11,245
Maintenance Cost	$63,563	$63,563	$47,672	$47,672
Midlife Costs	$0	$0	$0	$17,000
Registration Fee	$8,557	$8,402	$9,548	$10,558
Depreciation	-$12,109	-$10,909	-$14,400	-$20,278
Residual Value	-$9,237	-$8,321	-$10,984	-$15,467
Insurance Costs	$3,475	$3,130	$4,132	$5,818
Total Other Costs	$54,248	$55,865	$35,968	$45,303
EVSE Cost	$0	$0	$3,172	$0
Infrastructure Upgrade Cost	$0	$0	$28,318	$0
Total Infrastructure Cost	$0	$0	$31,489	$0
TOTAL	$159,704	$175,874	$143,273	$144,381
Payback Period vs Diesel (yr)	-	-	5.7	4.8

2035 Cargo Van

Figure 20: 2035 Cargo Van Total Cost of Ownership Comparison

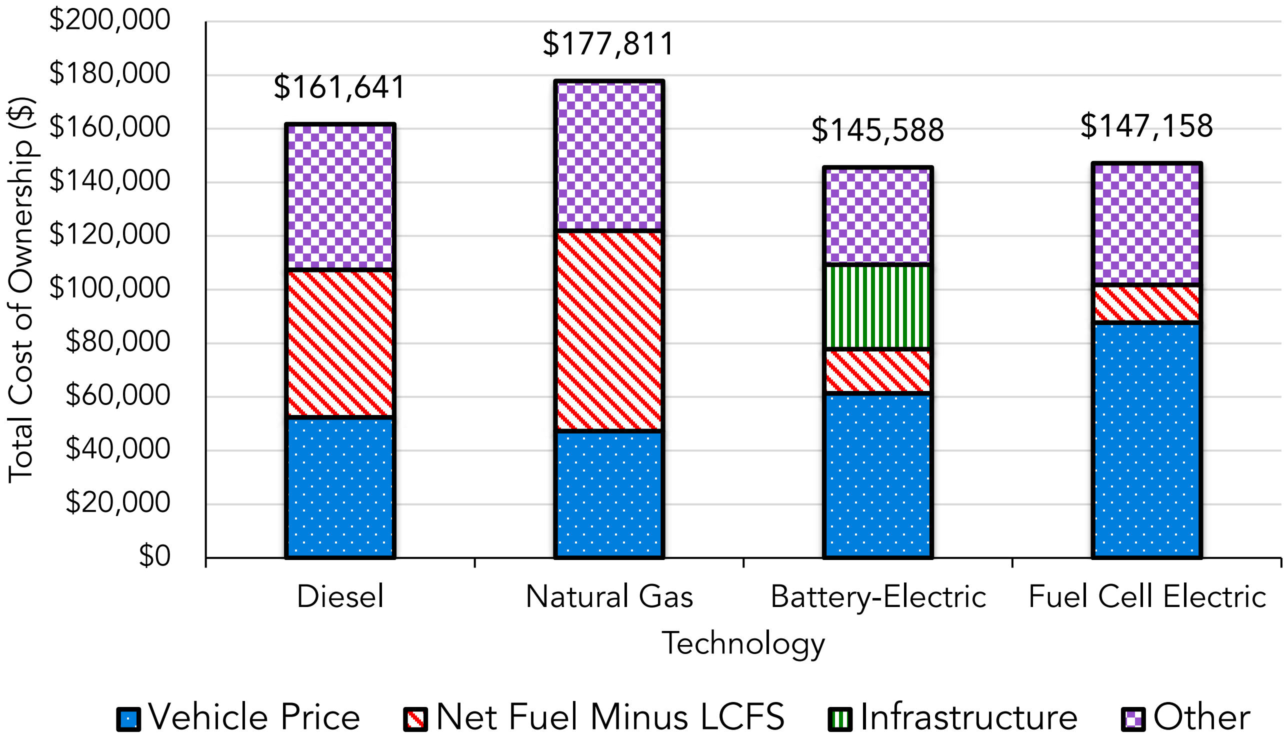

Figure 21: 2035 Cargo Van Cashflow Comparison

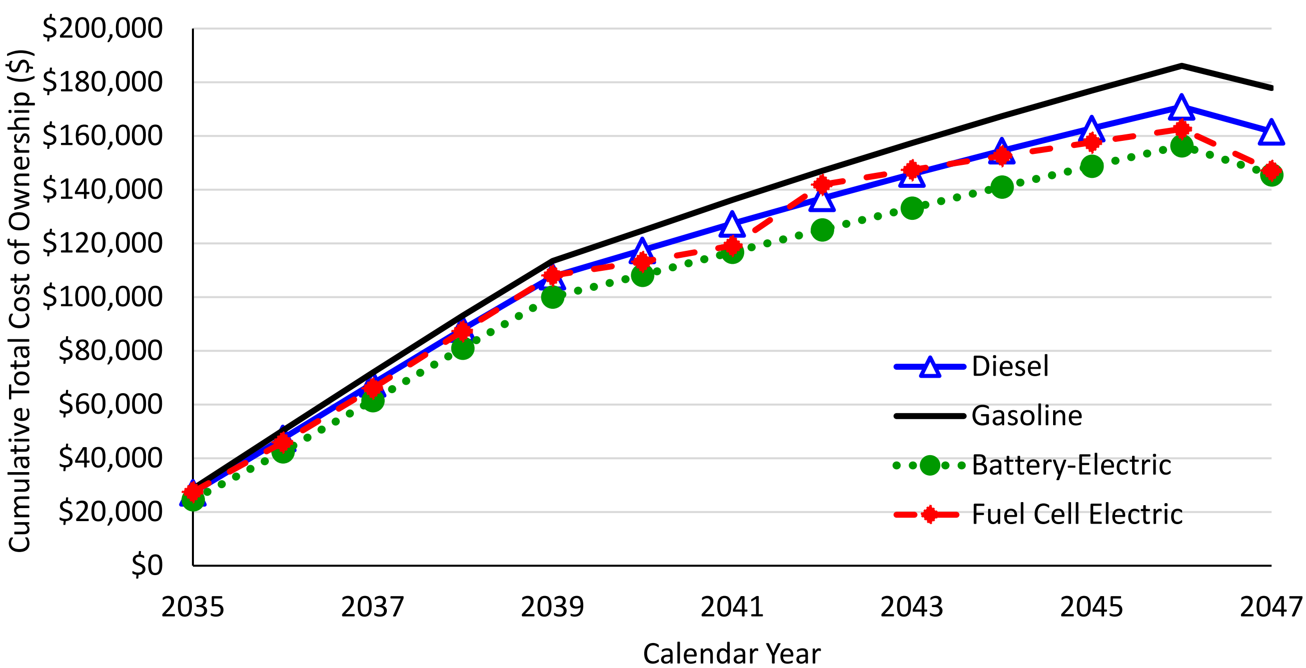

Table 19: 2035 Cargo Van Cost Breakdown

	Diesel	Gasoline	Battery-Electric	Fuel Cell Electric
Total Miles	188,600	188,600	188,600	188,600
Operating Years	12	12	12	12
Energy Storage	-	-	80 kWh	10 kWh/10 kg H2
Vehicle Power	-	-	200 kW	200 kW/100 kWFC
Vehicle Price	$40,364	$36,364	$47,174	$67,489
Taxes	$3,229	$2,909	$3,774	$5,399
Financing Costs	$8,858	$7,980	$10,352	$14,811
Total Vehicle Cost	$52,451	$47,253	$61,300	$87,698
Fuel Economy	15.3 mpg	11.7 mpg	2 mi./kWh	47.2 mi./kg
Unit Fuel Cost	$4.39/gal	$4.65/gal	$0.25/kWh	$5/kg
Fuel Cost	$54,249	$74,693	$23,505	$19,961
DEF Consumption	$693	$0	$0	$0
LCFS Revenue	$0	$0	-$7,009	-$5,847
Total Fuel Cost	$54,942	$74,693	$16,497	$14,114
Maintenance Cost	$63,563	$63,563	$47,672	$47,672
Midlife Costs	$0	$0	$0	$17,000
Registration Fee	$8,557	$8,402	$9,516	$10,554
Depreciation	-$12,109	-$10,909	-$14,152	-$20,247
Residual Value	-$9,237	-$8,321	-$10,795	-$15,444
Insurance Costs	$3,475	$3,130	$4,061	$5,809
Total Other Costs	$54,248	$55,865	$36,302	$45,345
EVSE Cost	$0	$0	$3,172	$0
Infrastructure Upgrade Cost	$0	$0	$28,318	$0
Total Infrastructure Cost	$0	$0	$31,489	$0
TOTAL	$161,641	$177,811	$145,588	$147,158
Payback Period vs Diesel (yr)	-	-	5.6	4.7

2025 Walk-in Van

Figure 22: 2025 Walk-in Van Total Cost of Ownership Comparison

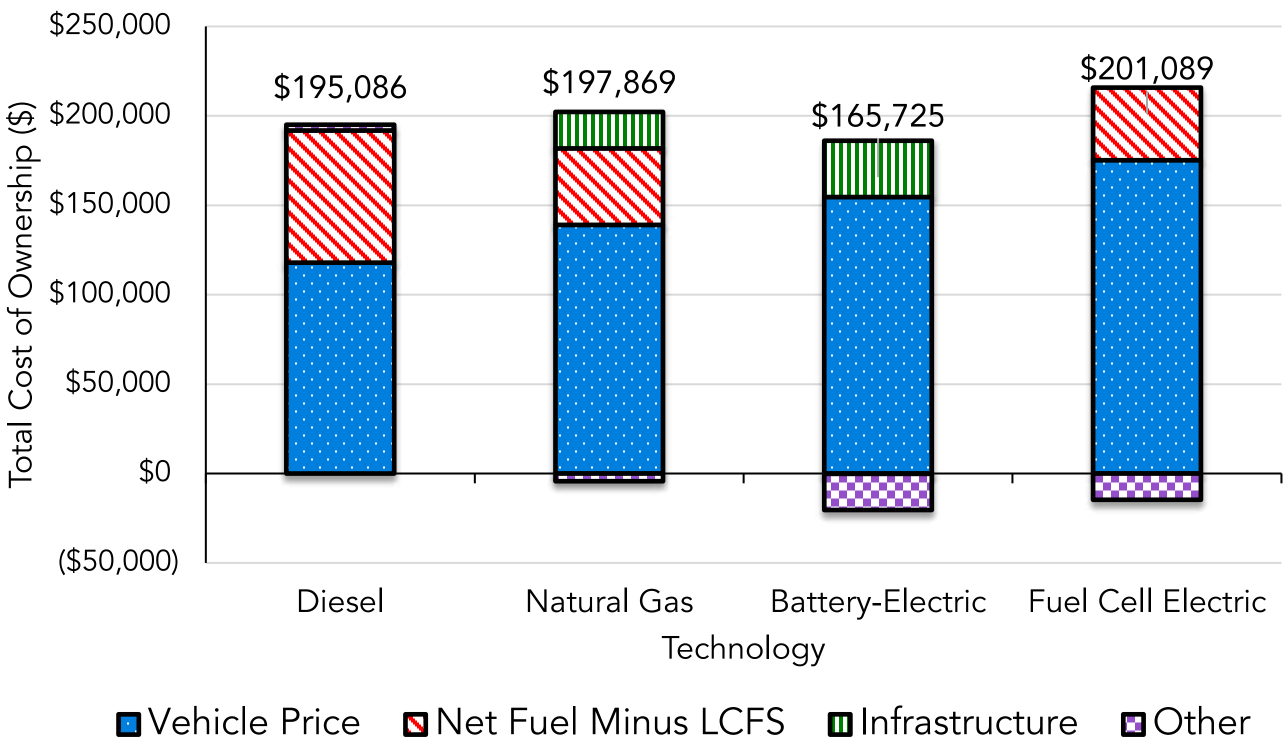

Figure 23: 2025 Walk-in Van Cashflow Comparison

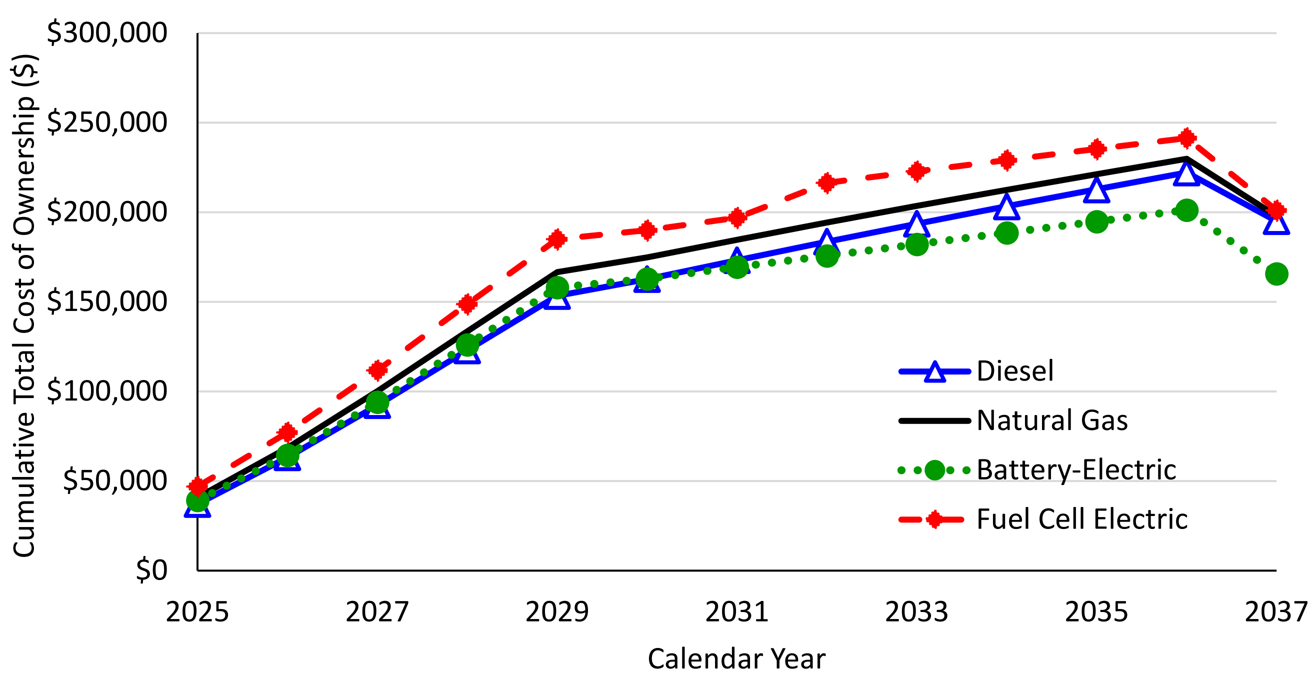

Table 20: 2025 Walk-in Van Cost Breakdown

	Diesel	Natural Gas	Battery-Electric	Fuel Cell Electric
Total Miles	163,979	163,979	163,979	163,979
Operating Years	12	12	12	12
Energy Storage	-	-	140 kWh	10 kWh/20 kg H2
Vehicle Power	-	-	150 kW	150 kW/75 kWFC
Vehicle Price	$90,709	$107,028	$118,971	$134,822
Taxes	$7,257	$8,562	$9,518	$10,786
Financing Costs	$19,906	$23,488	$26,108	$29,587
Total Vehicle Cost	$117,872	$139,078	$154,597	$175,194
Fuel Economy	9.1 mpg	7.6 mpg	1.13 mi./kWh	16.1 mi./kg
Unit Fuel Cost	$4.05/gal	$1.98/gal	$0.22/kWh	$5.54/kg
Fuel Cost	$72,923	$42,663	$32,510	$56,598
DEF Consumption	$1,009	$0	$0	$0
LCFS Revenue	$0	$0	-$32,764	-$16,019
Total Fuel Cost	$73,932	$42,663	-$253	$40,579
Maintenance Cost	$34,444	$34,444	$25,833	$25,833
Midlife Costs	$0	$0	$0	$12,750
Registration Fee	$14,272	$14,903	$13,649	$14,262
Depreciation	-$27,213	-$32,108	-$35,691	-$40,446
Residual Value	-$27,108	-$31,985	-$35,554	-$40,292
Insurance Costs	$8,886	$10,485	$11,655	$13,208
Total Other Costs	$3,282	-$4,261	-$20,108	-$14,684
EVSE Cost	$0	$0	$3,172	$0
Infrastructure Upgrade Cost	$0	$20,389	$28,318	$0
Total Infrastructure Cost	$0	$20,389	$31,489	$0
TOTAL	$195,086	$197,869	$165,725	$201,089
Payback Period vs Diesel (yr)	-	-	8.1	21.4

2030 Walk-in Van

Figure 24: 2030 Walk-in Van Total Cost of Ownership Comparison

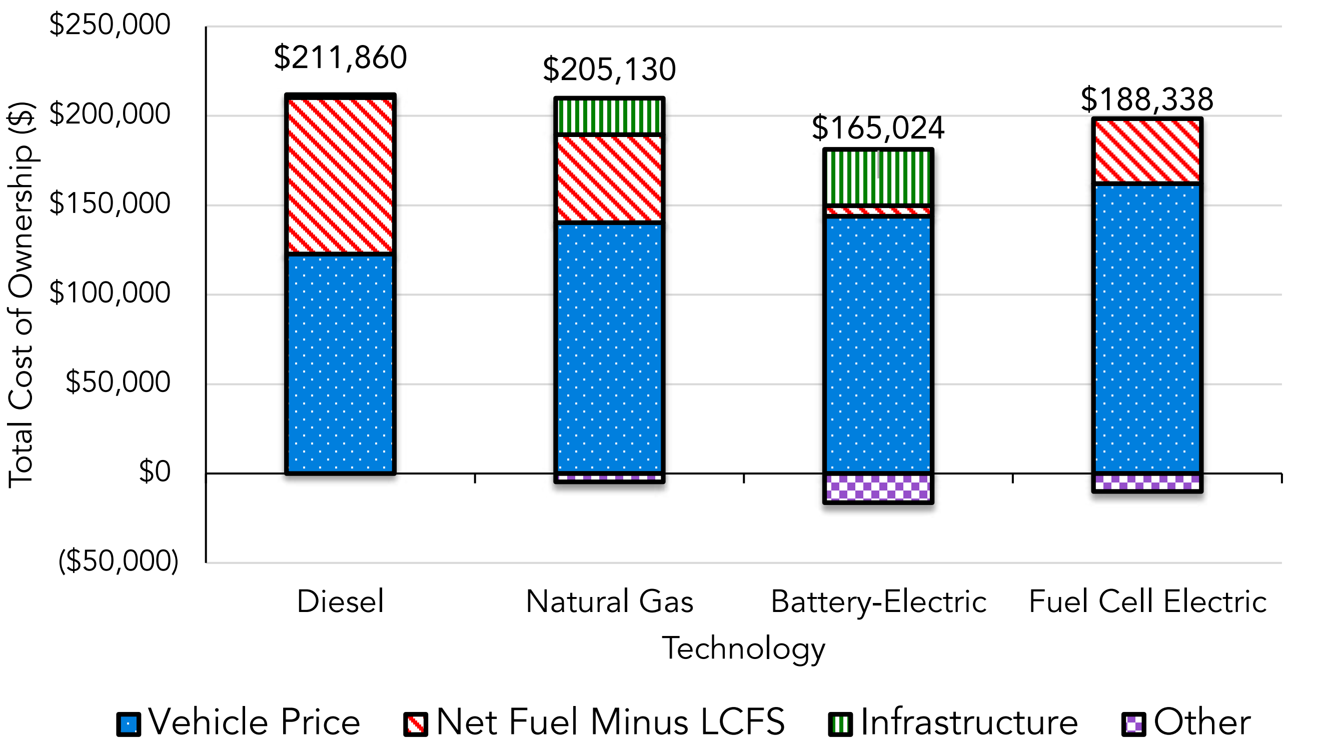

Figure 25: 2030 Walk-in Van Cashflow Comparison

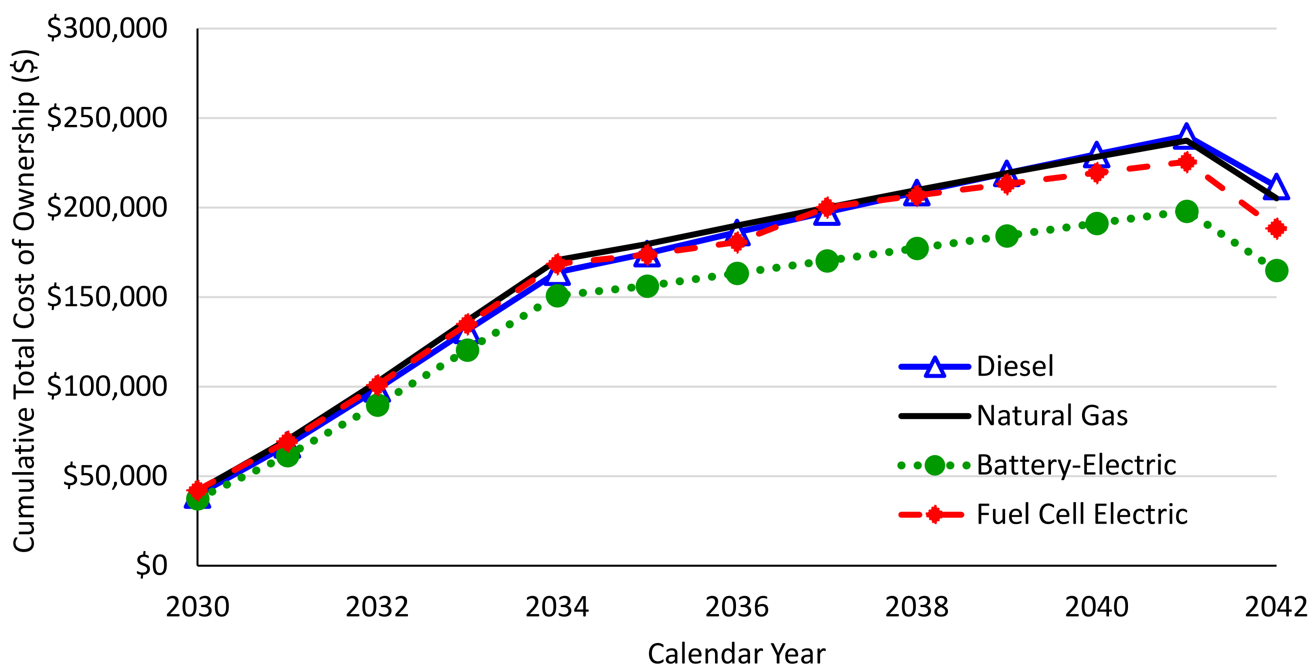

Table 21: 2030 Walk-in Van Cost Breakdown

	Diesel	Natural Gas	Battery-Electric	Fuel Cell Electric
Total Miles	163,979	163,979	163,979	163,979
Operating Years	12	12	12	12
Energy Storage	-	-	140 kWh	10 kWh/20 kg H2
Vehicle Power	-	-	150 kW	150 kW/75 kWFC
Vehicle Price	$94,403	$107,983	$110,644	$124,802
Taxes	$7,552	$8,639	$8,851	$9,984
Financing Costs	$20,717	$23,697	$24,281	$27,388
Total Vehicle Cost	$122,672	$140,319	$143,776	$162,175
Fuel Economy	8.1 mpg	6.5 mpg	1.2 mi./kWh	17 mi./kg
Average Unit Fuel Cost	$4.25/gal	$1.95/gal	$0.23/kWh	$5/kg
Fuel Cost	$86,473	$49,125	$31,145	$48,204
DEF Consumption	$1,141	$0	$0	$0
LCFS Revenue	$0	$0	-$25,128	-$11,987
Total Fuel Cost	$87,614	$49,125	$6,017	$36,217
Maintenance Cost	$34,444	$34,444	$25,833	$25,833
Midlife Costs	$0	$0	$0	$12,750
Registration Fee	$14,415	$14,940	$13,327	$13,875
Depreciation	-$28,321	-$32,395	-$33,193	-$37,441
Residual Value	-$28,212	-$32,271	-$33,066	-$37,297
Insurance Costs	$9,248	$10,579	$10,839	$12,226
Total Other Costs	$1,575	-$4,702	-$16,259	-$10,053
EVSE Cost	$0	$0	$3,172	$0
Infrastructure Upgrade Cost	$0	$20,389	$28,318	$0
Total Infrastructure Cost	$0	$20,389	$31,489	$0
TOTAL	$211,860	$205,130	$165,024	$188,338
Payback Period vs Diesel (yr)	-	-	5.7	6.7

2035 Walk-in Van

Figure 26: 2035 Walk-in Van Total Cost of Ownership Comparison

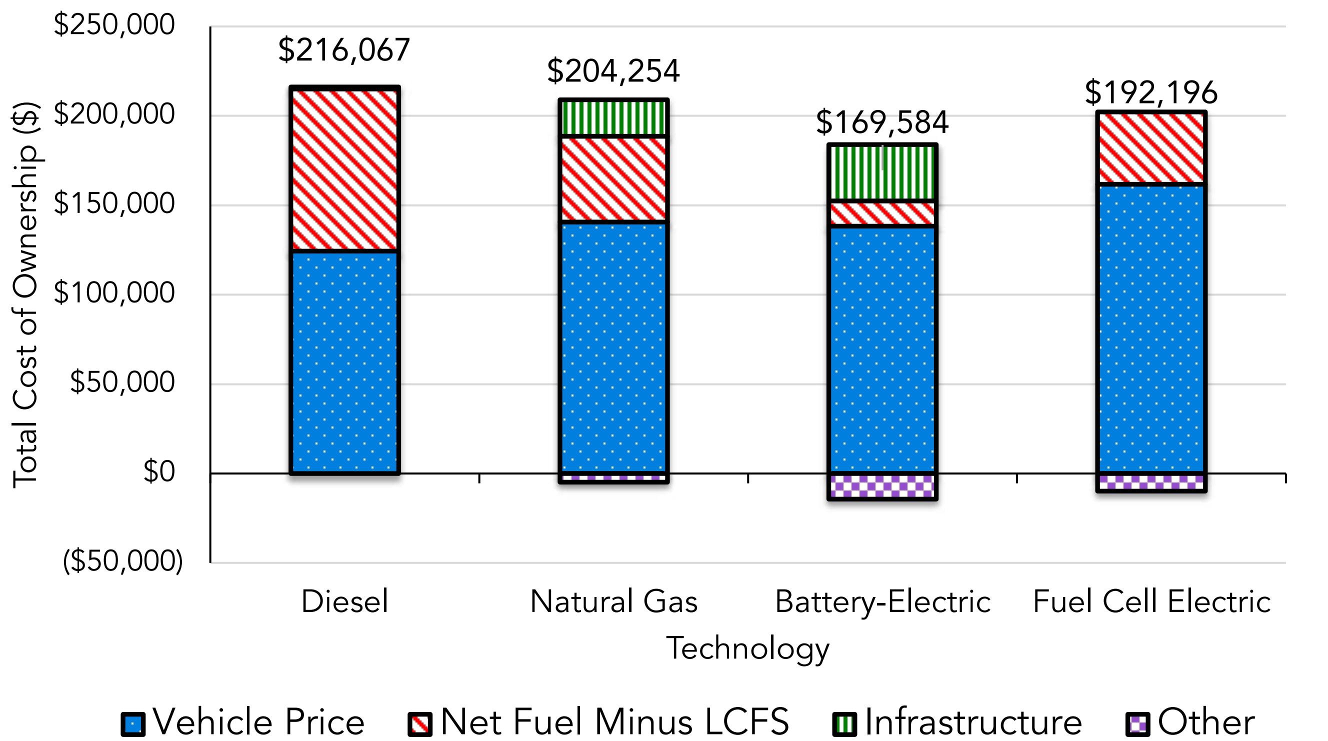

Figure 27: 2035 Walk-in Van Cashflow Comparison

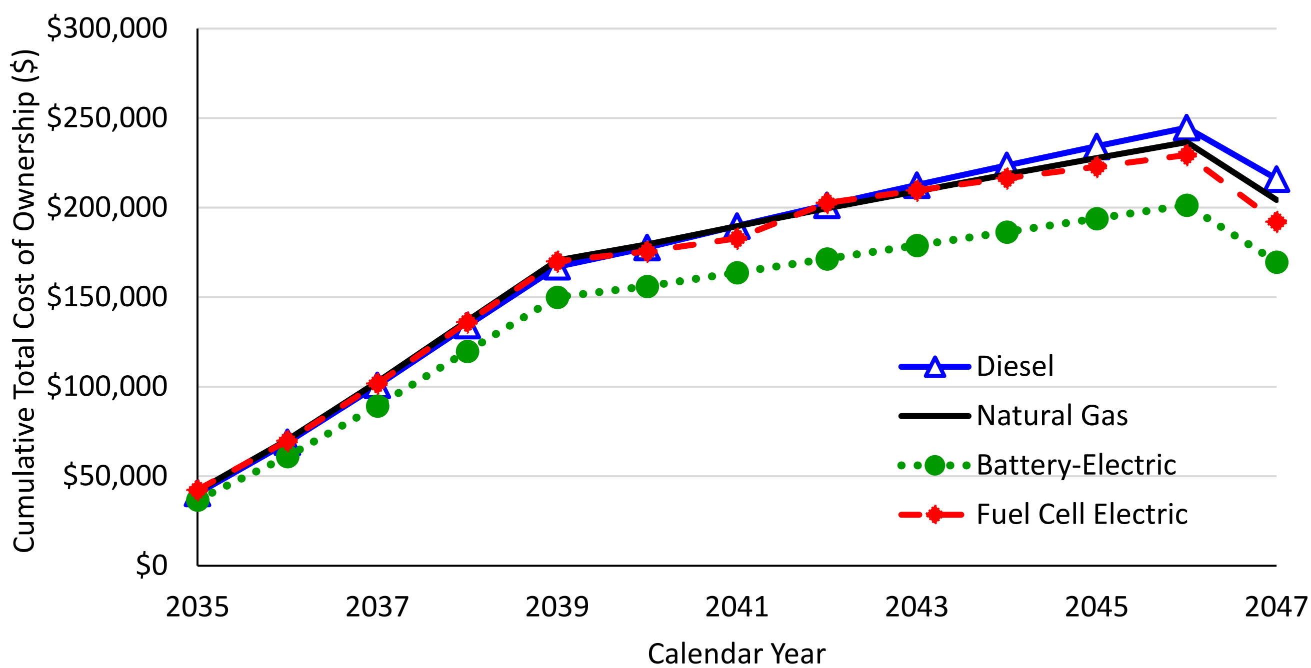

Table 22: 2035 Walk-in Van Cost Breakdown

	Diesel	Natural Gas	Battery-Electric	Fuel Cell Electric
Total Miles	163,979	163,979	163,979	163,979
Operating Years	12	12	12	12
Energy Storage	-	-	140 kWh	10 kWh/20 kg H2
Vehicle Power	-	-	150 kW	150 kW/75 kWFC
Vehicle Price	$95,703	$108,177	$106,486	$124,505
Taxes	$7,656	$8,654	$8,519	$9,960
Financing Costs	$21,002	$23,740	$23,369	$27,323
Total Vehicle Cost	$124,362	$140,571	$138,373	$161,789
Fuel Economy	8.1 mpg	6.5 mpg	1.2 mi./kWh	17 mi./kg
Average Unit Fuel Cost	$4.4/gal	$1.91/gal	$0.22/kWh	$5/kg
Fuel Cost	$89,591	$48,086	$30,579	$48,204
DEF Consumption	$1,141	$0	$0	$0
LCFS Revenue	$0	$0	-$16,520	-$7,881
Total Fuel Cost	$90,732	$48,086	$14,059	$40,324
Maintenance Cost	$34,444	$34,444	$25,833	$25,833
Midlife Costs	$0	$0	$0	$12,750
Registration Fee	$14,465	$14,948	$13,166	$13,863
Depreciation	-$28,711	-$32,453	-$31,946	-$37,352
Residual Value	-$28,601	-$32,329	-$31,823	-$37,209
Insurance Costs	$9,376	$10,598	$10,432	$12,197
Total Other Costs	$974	-$4,792	-$14,337	-$9,916
EVSE Cost	$0	$0	$3,172	$0
Infrastructure Upgrade Cost	$0	$20,389	$28,318	$0
Total Infrastructure Cost	$0	$20,389	$31,489	$0
TOTAL	$216,067	$204,254	$169,584	$192,196
Payback Period vs Diesel (yr)	-	-	5.0	6.2

2025 Bucket Truck

Figure 28: 2025 Bucket Truck Total Cost of Ownership Comparison

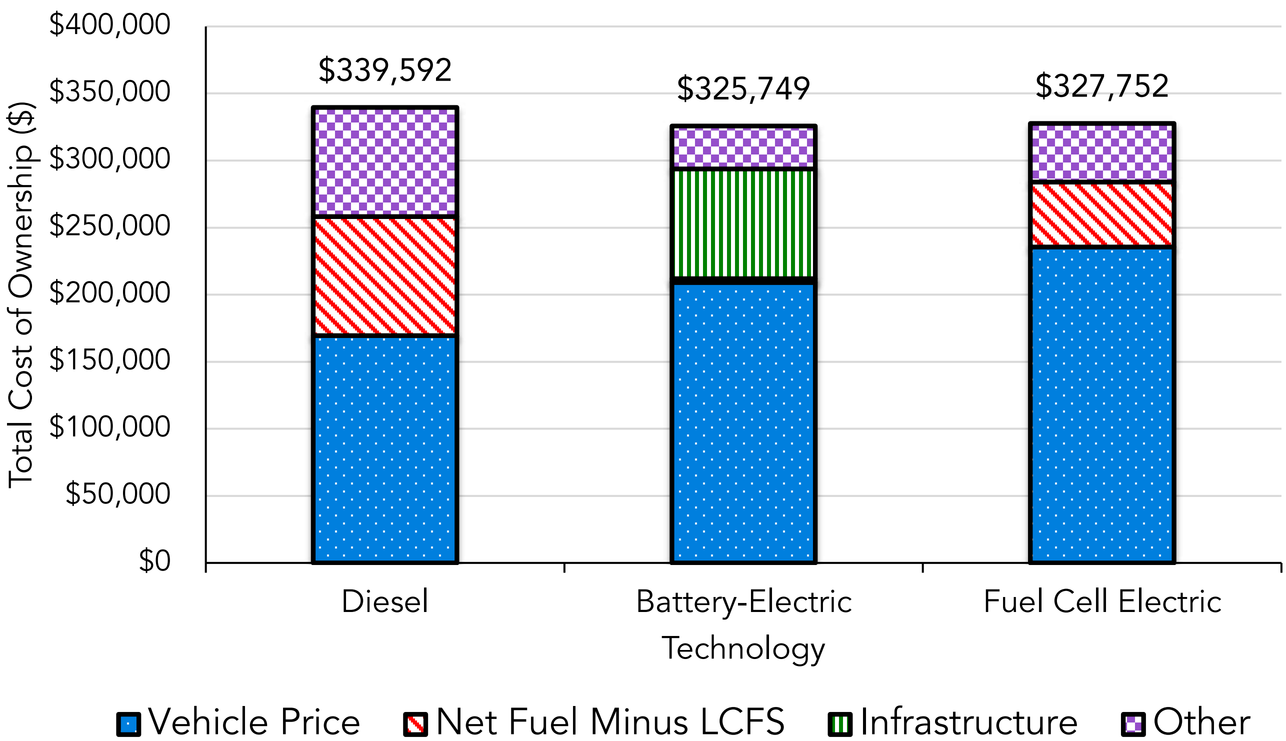

Figure 29: 2025 Bucket Truck Cashflow Comparison

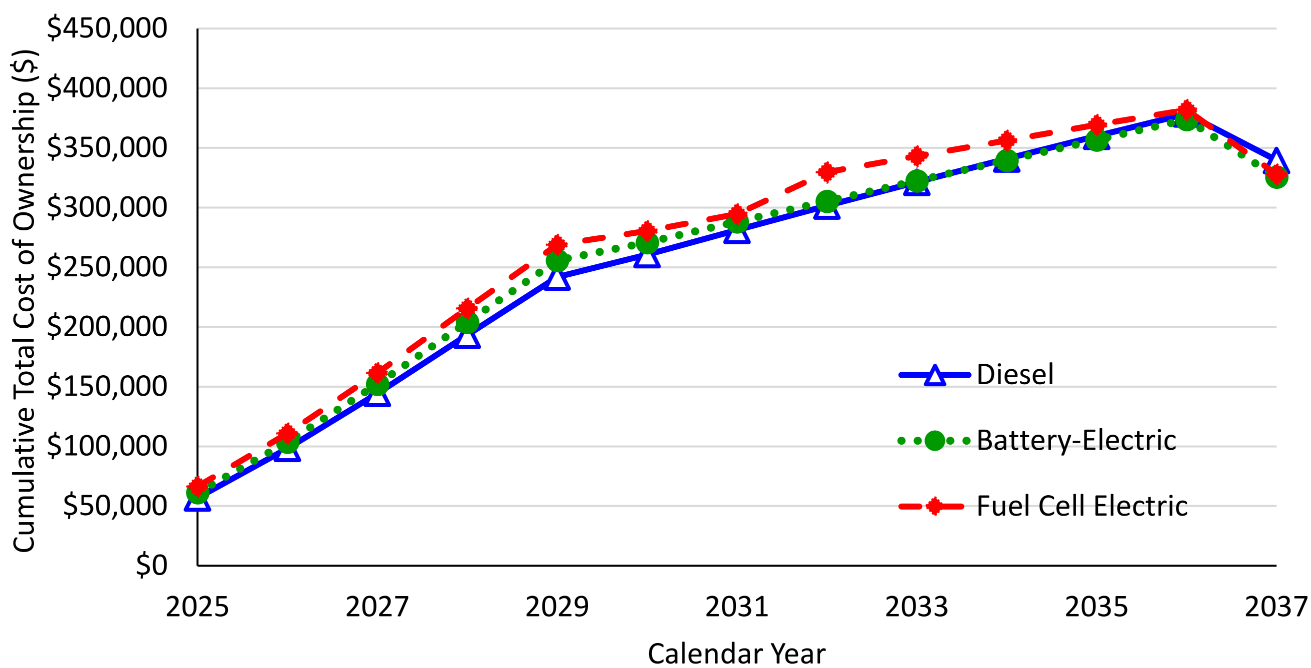

Table 23: 2025 Bucket Truck Cost Breakdown

	Diesel	Battery-Electric	Fuel Cell Electric
Total Miles	185,153	185,153	185,153
Operating Years	12	12	12
Energy Storage	-	200 kWh	10 kWh/20 kg H2
Vehicle Power	-	250 kW	250 kW/125 kWFC
Vehicle Price	$130,491	$160,936	$181,282
Taxes	$10,439	$12,875	$14,503
Financing Costs	$28,637	$35,318	$39,783
Total Vehicle Cost	$169,567	$209,128	$235,567
Fuel Economy	8.6 mpg	0.76 mi./kWh	15.1 mi./kg
Average Unit Fuel Cost	$4.06/gal	$0.24/kWh	$5.5/kg
Fuel Cost	$87,571	$57,929	$67,626
DEF Consumption	$1,209	$0	$0
LCFS Revenue	$0	-$55,184	-$19,154
Total Fuel Cost	$88,780	$2,745	$48,472
Maintenance Cost	$129,607	$97,205	$97,205
Midlife Costs	$0	$0	$21,250
Registration Fee	$16,999	$15,272	$16,059
Depreciation	-$39,147	-$48,281	-$54,385
Residual Value	-$38,997	-$48,096	-$54,176
Insurance Costs	$12,784	$15,766	$17,760
Total Other Costs	$81,245	$31,867	$43,713
EVSE Cost	$0	$32,169	$0
Infrastructure Upgrade Cost	$0	$49,839	$0
Total Infrastructure Cost	$0	$82,009	$0
TOTAL	$339,592	$325,749	$327,752
Payback Period vs Diesel (yr)	-	11.2	14.0

2030 Bucket Truck

Figure 30: 2030 Bucket Truck Total Cost of Ownership Comparison

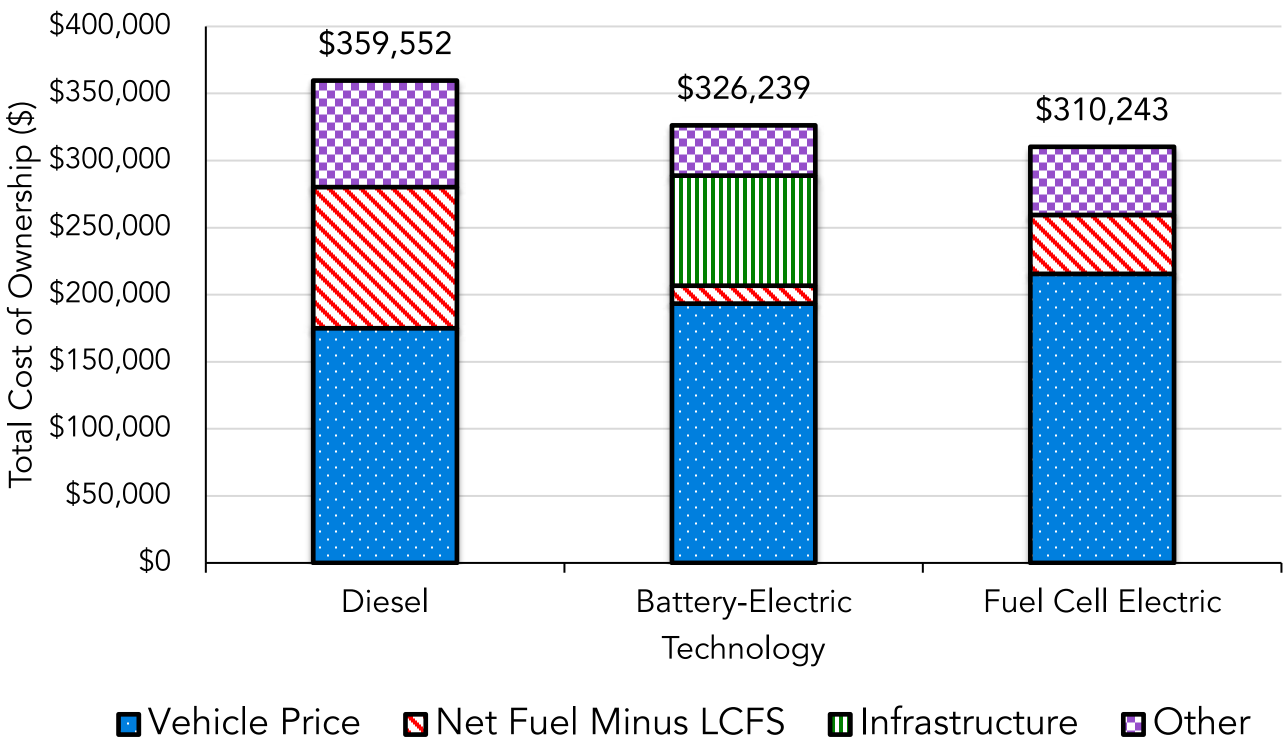

Figure 31: 2030 Bucket Truck Cashflow Comparison

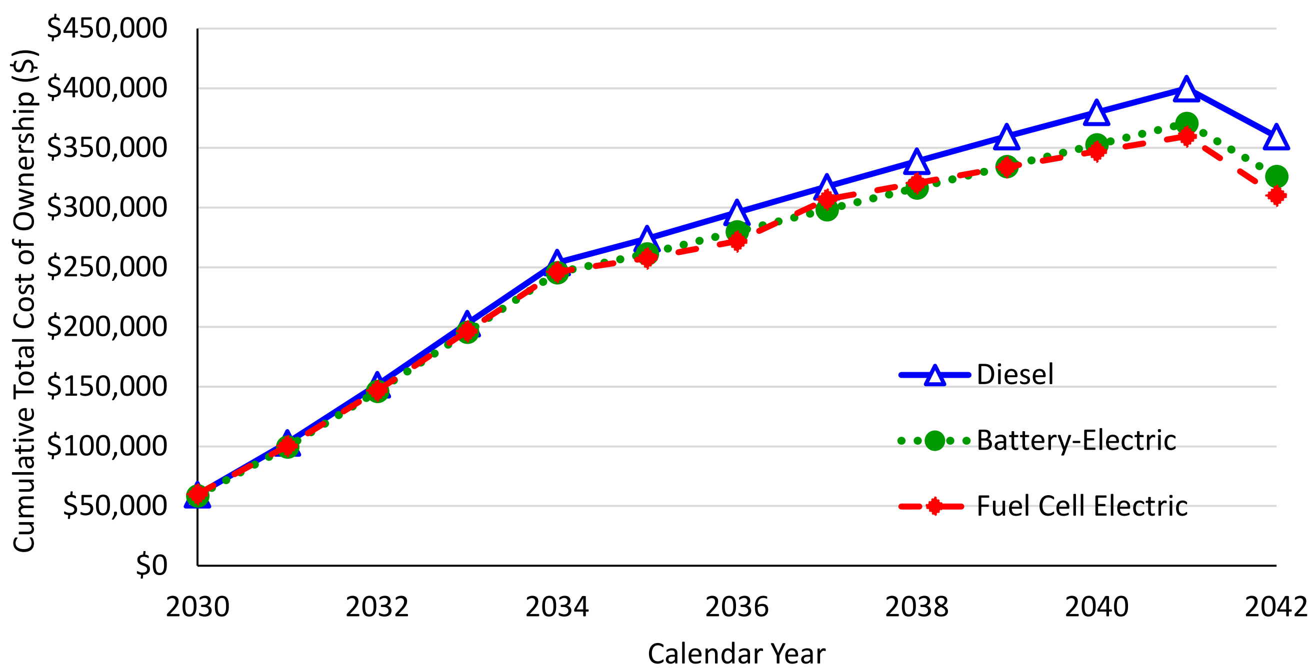

Table 24: 2030 Bucket Truck Cost Breakdown

	Diesel	Battery-Electric	Fuel Cell Electric
Total Miles	185,153	185,153	185,153
Operating Years	12	12	12
Energy Storage	-	200 kWh	10 kWh/20 kg H2
Vehicle Power	-	250 kW	250 kW/125 kWFC
Vehicle Price	$134,725	$148,770	$165,909
Taxes	$10,778	$11,902	$13,273
Financing Costs	$29,566	$32,648	$36,409
Total Vehicle Cost	$175,069	$193,319	$215,591
Fuel Economy	7.6 mpg	0.8 mi./kWh	15.9 mi./kg
Average Unit Fuel Cost	$4.25/gal	$0.24/kWh	$5/kg
Fuel Cost	$103,828	$55,380	$58,071
DEF Consumption	$1,367	$0	$0
LCFS Revenue	$0	-$41,960	-$14,237
Total Fuel Cost	$105,195	$13,420	$43,834
Maintenance Cost	$129,607	$97,205	$97,205
Midlife Costs	$0	$0	$21,250
Registration Fee	$17,162	$14,802	$15,465
Depreciation	-$40,418	-$44,631	-$49,773
Residual Value	-$40,263	-$44,460	-$49,582
Insurance Costs	$13,199	$14,574	$16,254
Total Other Costs	$79,288	$37,491	$50,818
EVSE Cost	$0	$32,169	$0
Infrastructure Upgrade Cost	$0	$49,839	$0
Total Infrastructure Cost	$0	$82,009	$0
TOTAL	$359,552	$326,239	$310,243
Payback Period vs Diesel (yr)	-	8.7	5.0

2035 Bucket Truck

Figure 32: 2035 Bucket Truck Total Cost of Ownership Comparison

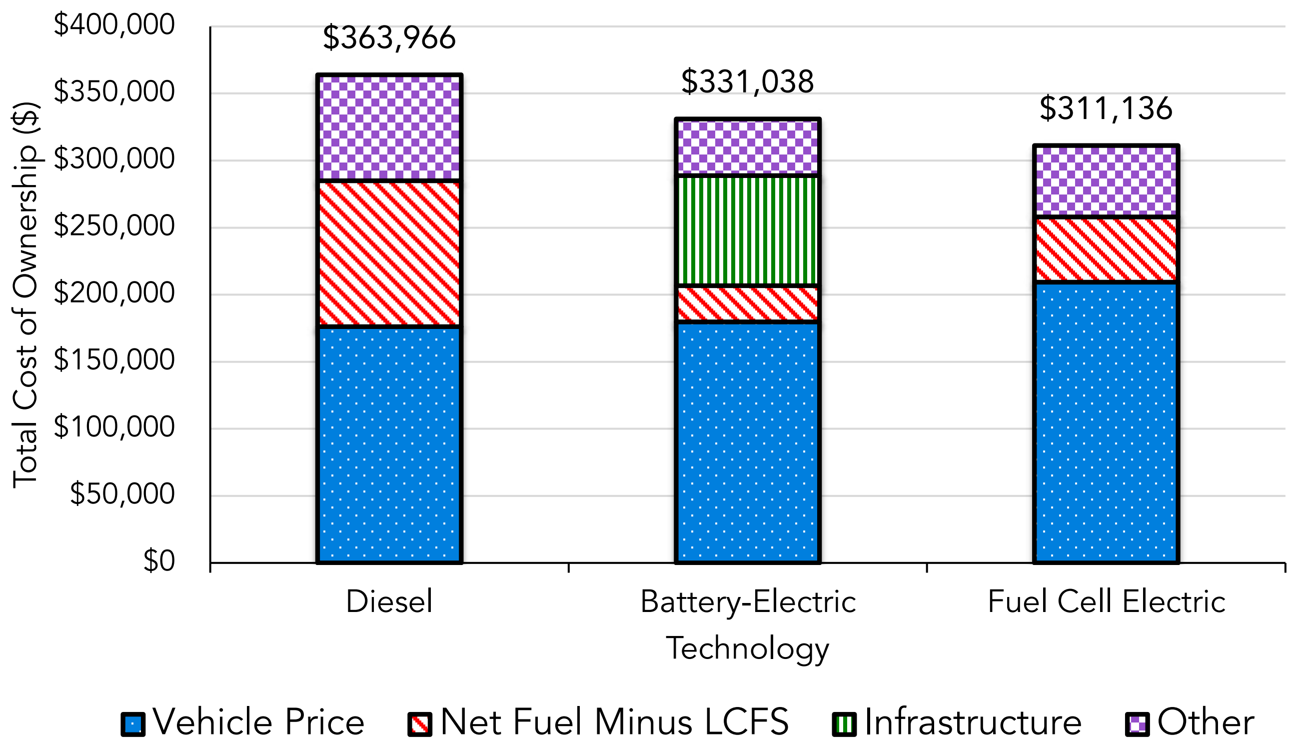

Figure 33: 2035 Bucket Truck Cashflow Comparison

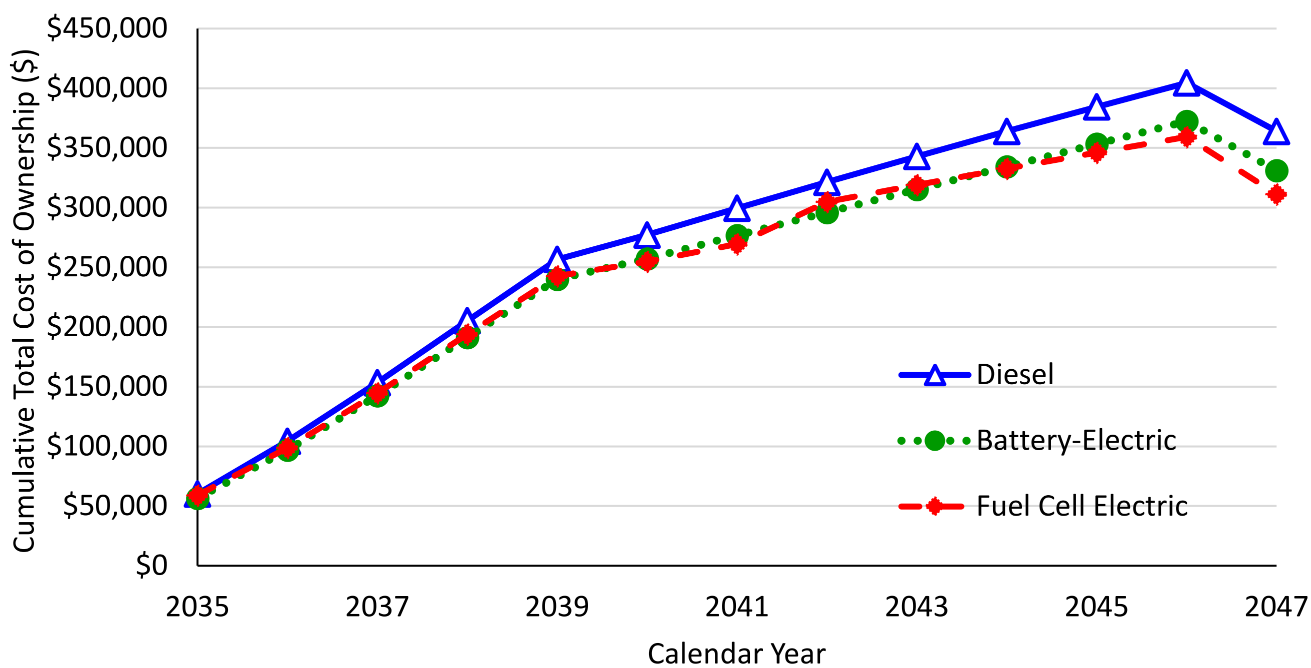

Table 25: 2035 Bucket Truck Cost Breakdown

	Diesel	Battery-Electric	Fuel Cell Electric
Total Miles	185,153	185,153	185,153
Operating Years	12	12	12
Energy Storage	-	200 kWh	10 kWh/20 kg H2
Vehicle Power	-	250 kW	250 kW/125 kWFC
Vehicle Price	$135,585	$138,243	$161,025
Taxes	$10,847	$11,059	$12,882
Financing Costs	$29,755	$30,338	$35,338
Total Vehicle Cost	$176,186	$179,640	$209,245
Fuel Economy	7.6 mpg	0.8 mi./kWh	15.9 mi./kg
Average Unit Fuel Cost	$4.4/gal	$0.23/kWh	$5/kg
Fuel Cost	$107,522	$54,310	$58,071
DEF Consumption	$1,367	$0	$0
LCFS Revenue	$0	-$27,277	-$9,255
Total Fuel Cost	$108,889	$27,033	$48,816
Maintenance Cost	$129,607	$97,205	$97,205
Midlife Costs	$0	$0	$21,250
Registration Fee	$17,196	$14,395	$15,276
Depreciation	-$40,676	-$41,473	-$48,308
Residual Value	-$40,520	-$41,314	-$48,123
Insurance Costs	$13,283	$13,543	$15,775
Total Other Costs	$78,890	$42,356	$53,076
EVSE Cost	$0	$32,169	$0
Infrastructure Upgrade Cost	$0	$49,839	$0
Total Infrastructure Cost	$0	$82,009	$0
TOTAL	$363,966	$331,038	$311,136
Payback Period vs Diesel (yr)	-	7.8	4.0

2025 Refuse Packer

Figure 34: 2025 Refuse Packer Total Cost of Ownership Comparison

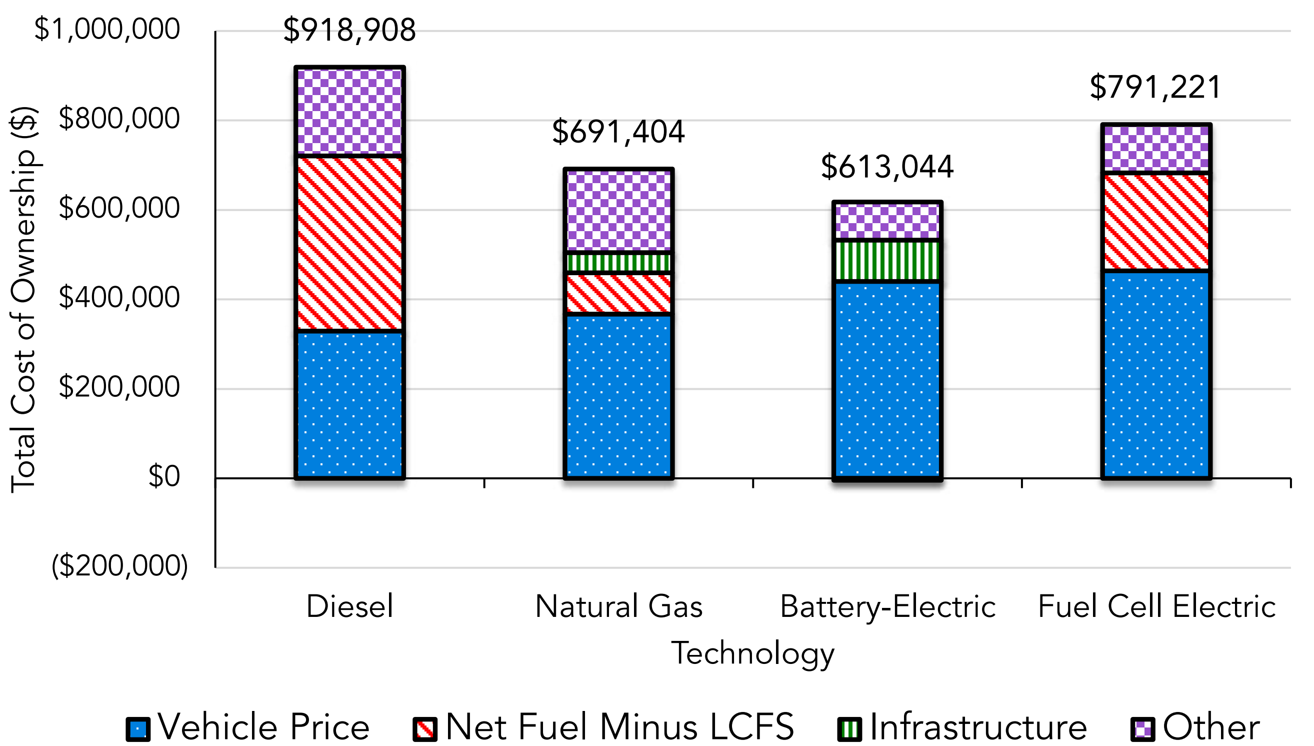

Figure 35: 2025 Refuse Packer Cashflow Comparison

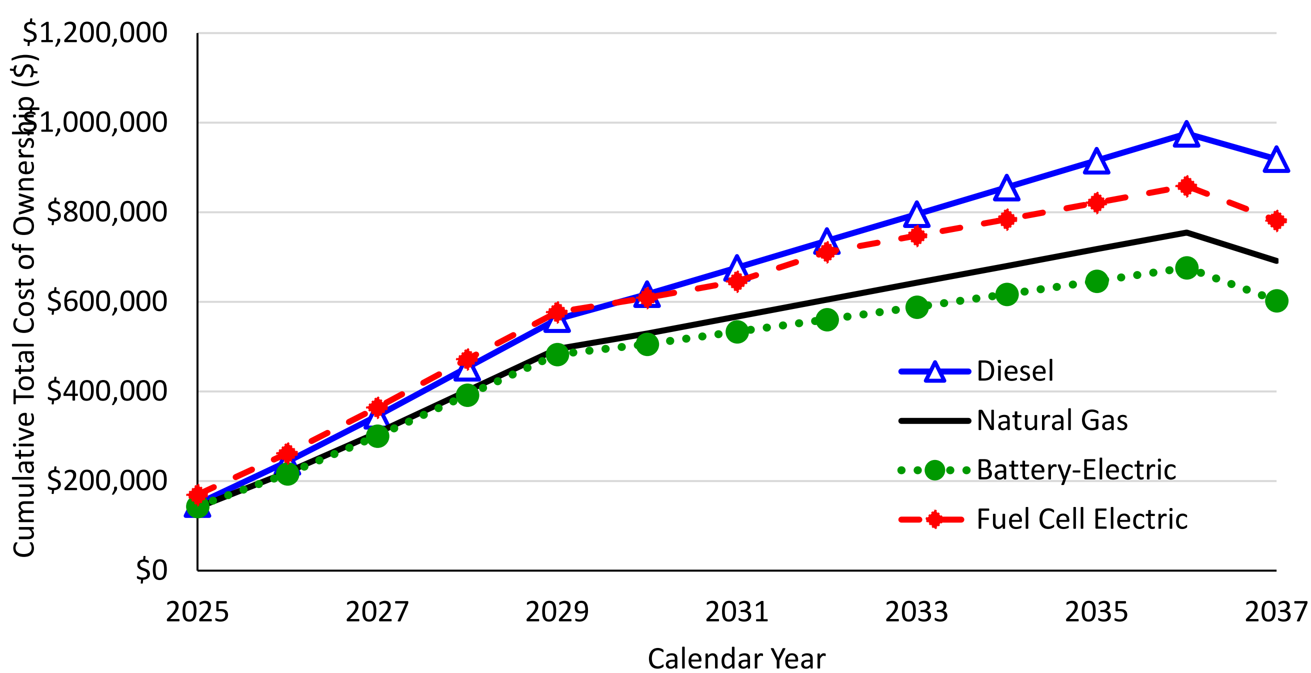

Table 26: 2025 Refuse Packer Cost Breakdown

	Diesel	Natural Gas	Battery-Electric	Fuel Cell Electric
Total Miles	290,640	290,640	290,640	290,640
Operating Years	12	12	12	12
Energy Storage	-	-	410 kWh	10 kWh/40 kg H2
Vehicle Power	-	-	350 kW	350 kW/175 kWFC
Vehicle Price	$231,783	$258,823	$299,932	$316,578
Taxes	$46,357	$51,765	$59,986	$63,316
Financing Costs	$50,866	$56,800	$65,821	$69,474
Total Vehicle Cost	$329,005	$367,387	$425,739	$449,368
Fuel Economy	3.1 mpg	6.3 mpg	0.38 mi./kWh	5.2 mi./kg
Average Unit Fuel Cost	$4.06/gal	$1.98/gal	$0.22/kWh	$5.48/kg
Fuel Cost	$386,373	$91,777	$167,757	$305,878
DEF Consumption	$5,324	$0	$0	$0
LCFS Revenue	$0	$0	-$172,447	-$86,513
Total Fuel Cost	$391,697	$91,777	-$4,690	$219,365
Maintenance Cost	$274,213	$274,213	$205,660	$205,660
Midlife Costs	$0	$0	$0	$29,750
Registration Fee	$29,604	$30,650	$20,648	$21,292
Depreciation	-$69,535	-$77,647	-$89,979	-$94,973
Residual Value	-$56,674	-$63,285	-$73,337	-$77,407
Insurance Costs	$20,597	$23,000	$26,653	$28,132
Total Other Costs	$198,206	$186,931	$89,645	$112,453
EVSE Cost	$0	$0	$42,477	$0
Infrastructure Upgrade Cost	$0	$45,309	$49,839	$0
Total Infrastructure Cost	$0	$45,309	$92,316	$0
TOTAL	$918,908	$691,404	$603,009	$781,186
Payback Period vs Diesel (yr)	-	-	4.8	9.4

2030 Refuse Packer

Figure 36: 2030 Refuse Packer Total Cost of Ownership Comparison

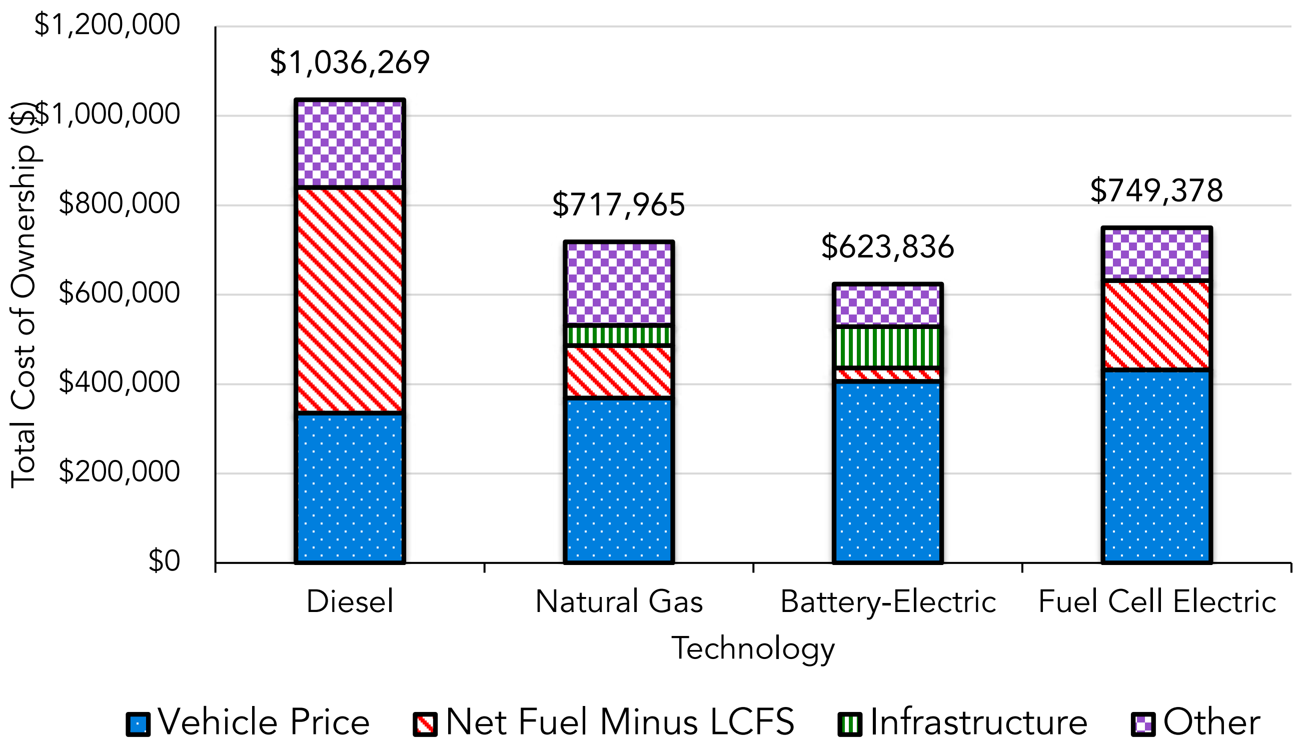

Figure 37: 2030 Refuse Packer Cashflow Comparison

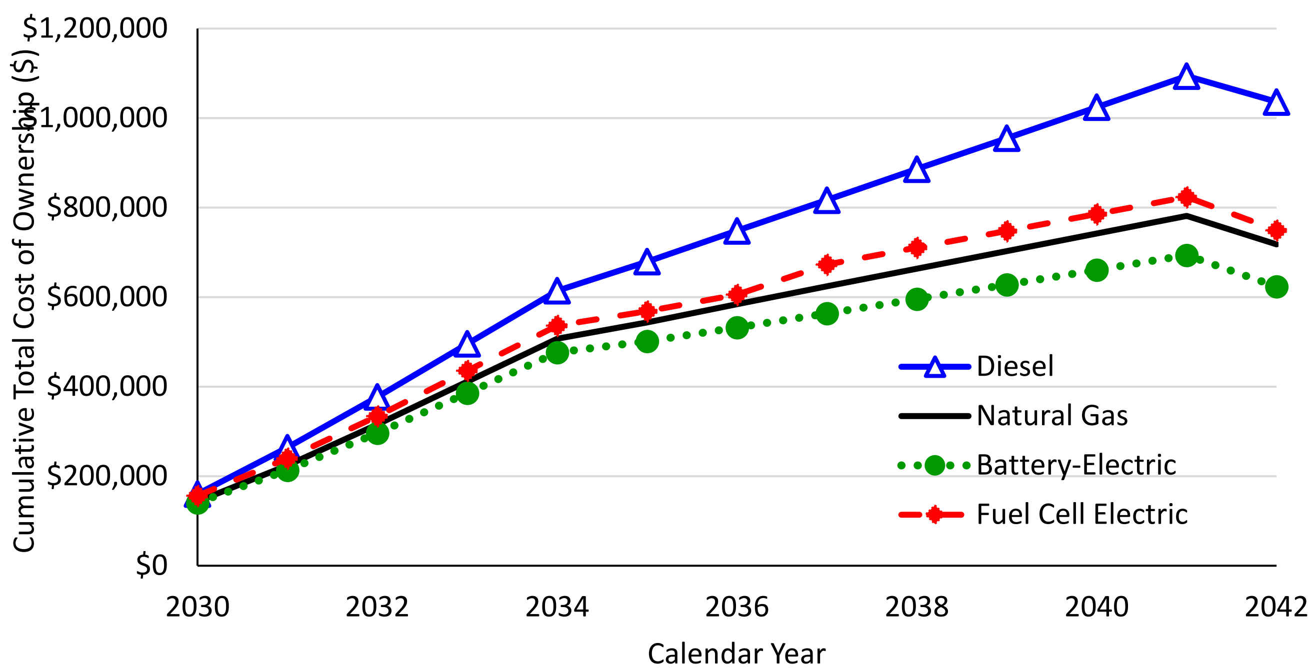

Table 27: 2030 Refuse Packer Cost Breakdown

	Diesel	Natural Gas	Battery-Electric	Fuel Cell Electric
Total Miles	290,640	290,640	290,640	290,640
Operating Years	12	12	12	12
Energy Storage	-	-	410 kWh	10 kWh/40 kg H2
Vehicle Power	-	-	350 kW	350 kW/175 kWFC
Vehicle Price	$236,085	$259,778	$286,264	$304,396
Taxes	$47,217	$51,956	$57,253	$60,879
Financing Costs	$51,810	$57,009	$62,822	$66,801
Total Vehicle Cost	$335,112	$368,743	$406,338	$432,075
Fuel Economy	2.5 mpg	4.8 mpg	0.4 mi./kWh	5.5 mi./kg
Average Unit Fuel Cost	$4.26/gal	$1.95/gal	$0.22/kWh	$5/kg
Fuel Cost	$498,194	$117,381	$160,168	$263,744
DEF Consumption	$6,551	$0	$0	$0
LCFS Revenue	$0	$0	-$130,330	-$63,975
Total Fuel Cost	$504,745	$117,381	$29,838	$199,769
Maintenance Cost	$274,213	$274,213	$205,660	$205,660
Midlife Costs	$0	$0	$0	$29,750
Registration Fee	$29,771	$30,687	$20,119	$20,821
Depreciation	-$70,826	-$77,933	-$85,879	-$91,319
Residual Value	-$57,726	-$63,519	-$69,995	-$74,428
Insurance Costs	$20,979	$23,085	$25,438	$27,050
Total Other Costs	$196,412	$186,533	$95,344	$117,533
EVSE Cost	$0	$0	$42,477	$0
Infrastructure Upgrade Cost	$0	$45,309	$49,839	$0
Total Infrastructure Cost	$0	$45,309	$92,316	$0
TOTAL	$1,036,269	$717,965	$623,836	$749,378
Payback Period vs Diesel (yr)	-	-	3.5	3.2

2035 Refuse Packer

Figure 38: 2035 Refuse Packer Total Cost of Ownership Comparison

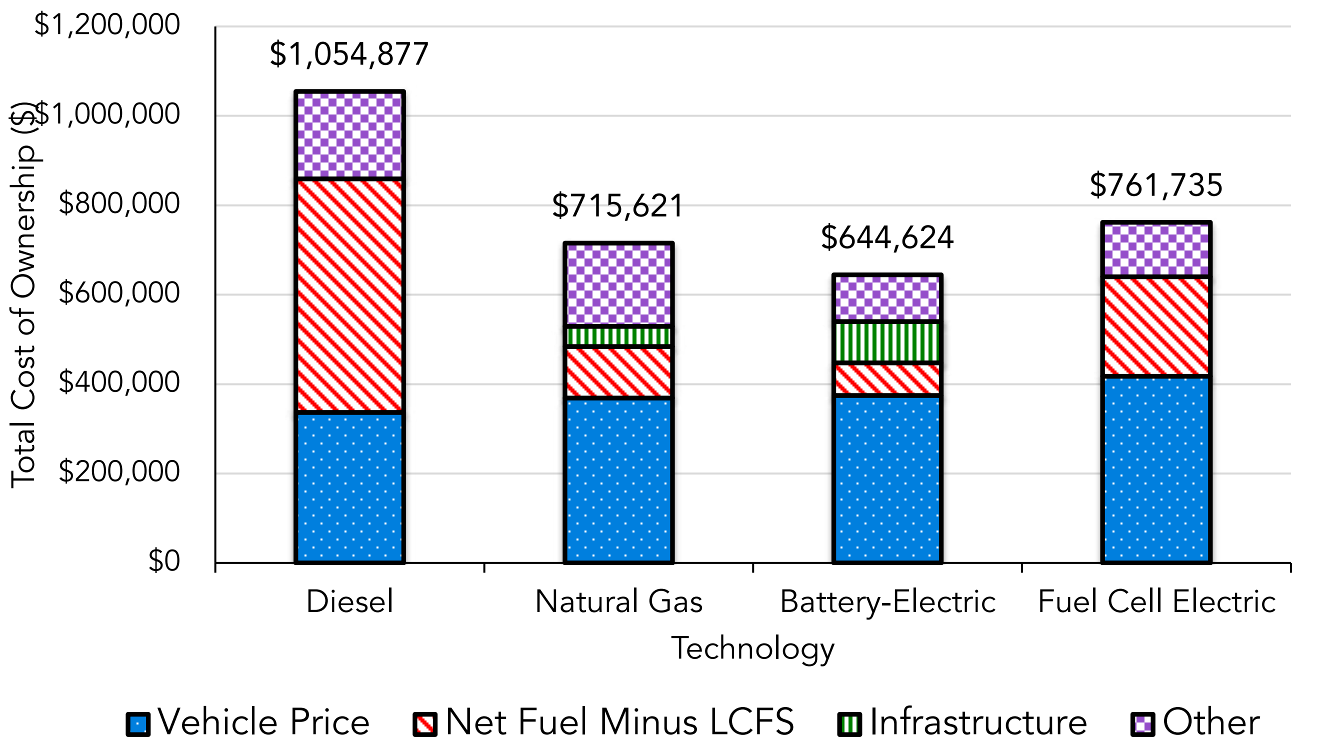

Figure 39: 2035 Refuse Packer Cashflow Comparison

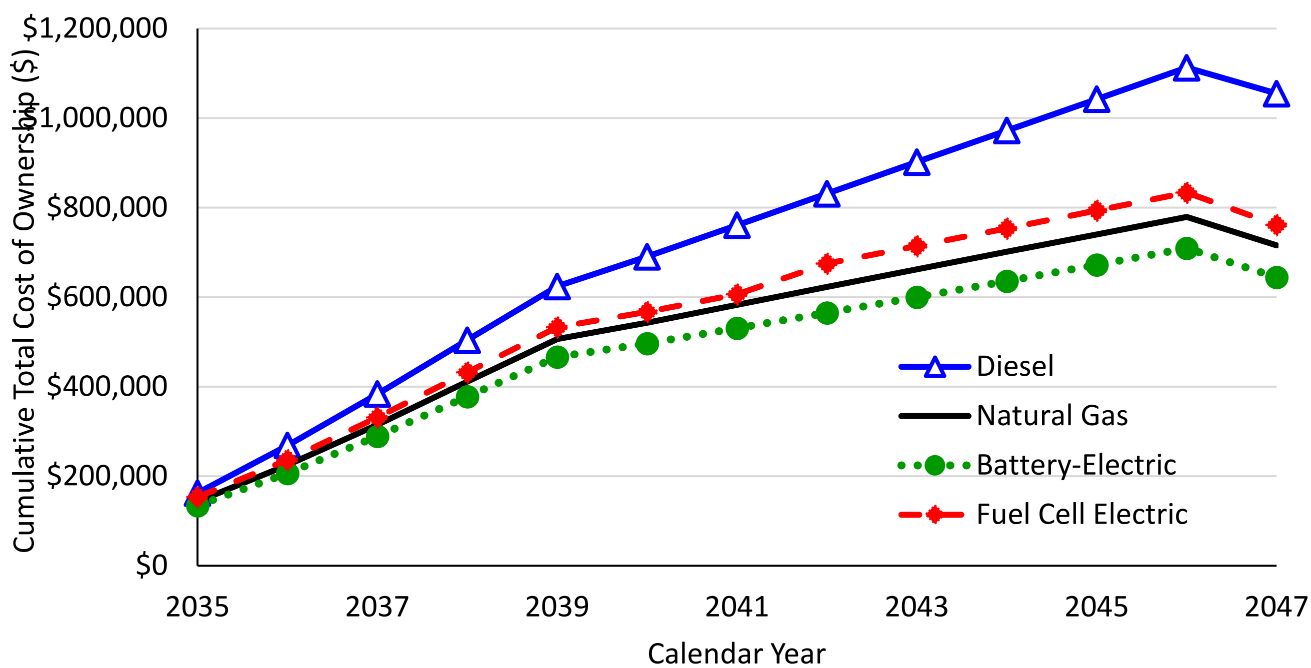

Table 28: 2035 Refuse Packer Cost Breakdown

	Diesel	Natural Gas	Battery-Electric	Fuel Cell Electric
Total Miles	290,640	290,640	290,640	290,640
Operating Years	12	12	12	12
Energy Storage	-	-	410 kWh	10 kWh/40 kg H2
Vehicle Power	-	-	350 kW	350 kW/175 kWFC
Vehicle Price	$237,140	$259,972	$264,077	$294,089
Taxes	$47,428	$51,994	$52,815	$58,818
Financing Costs	$52,041	$57,052	$57,953	$64,539
Total Vehicle Cost	$336,609	$369,018	$374,845	$417,445
Fuel Economy	2.5 mpg	4.8 mpg	0.4 mi./kWh	5.5 mi./kg
Average Unit Fuel Cost	$4.41/gal	$1.91/gal	$0.22/kWh	$5/kg
Fuel Cost	$515,744	$114,843	$156,974	$263,744
DEF Consumption	$6,551	$0	$0	$0
LCFS Revenue	$0	$0	-$84,106	-$41,285
Total Fuel Cost	$522,295	$114,843	$72,868	$222,459
Maintenance Cost	$274,213	$274,213	$205,660	$205,660
Midlife Costs	$0	$0	$0	$29,750
Registration Fee	$29,811	$30,694	$19,261	$20,422
Depreciation	-$71,142	-$77,992	-$79,223	-$88,227
Residual Value	-$57,983	-$63,566	-$64,570	-$71,908
Insurance Costs	$21,073	$23,102	$23,467	$26,134
Total Other Costs	$195,972	$186,452	$104,595	$121,831
EVSE Cost	$0	$0	$42,477	$0
Infrastructure Upgrade Cost	$0	$45,309	$49,839	$0
Total Infrastructure Cost	$0	$45,309	$92,316	$0
TOTAL	$1,054,877	$715,621	$644,624	$761,735
Payback Period vs Diesel (yr)	-	-	2.9	2.6

2025 Day Cab Tractor

Figure 40: 2025 Day Cab Tractor Total Cost of Ownership Comparison

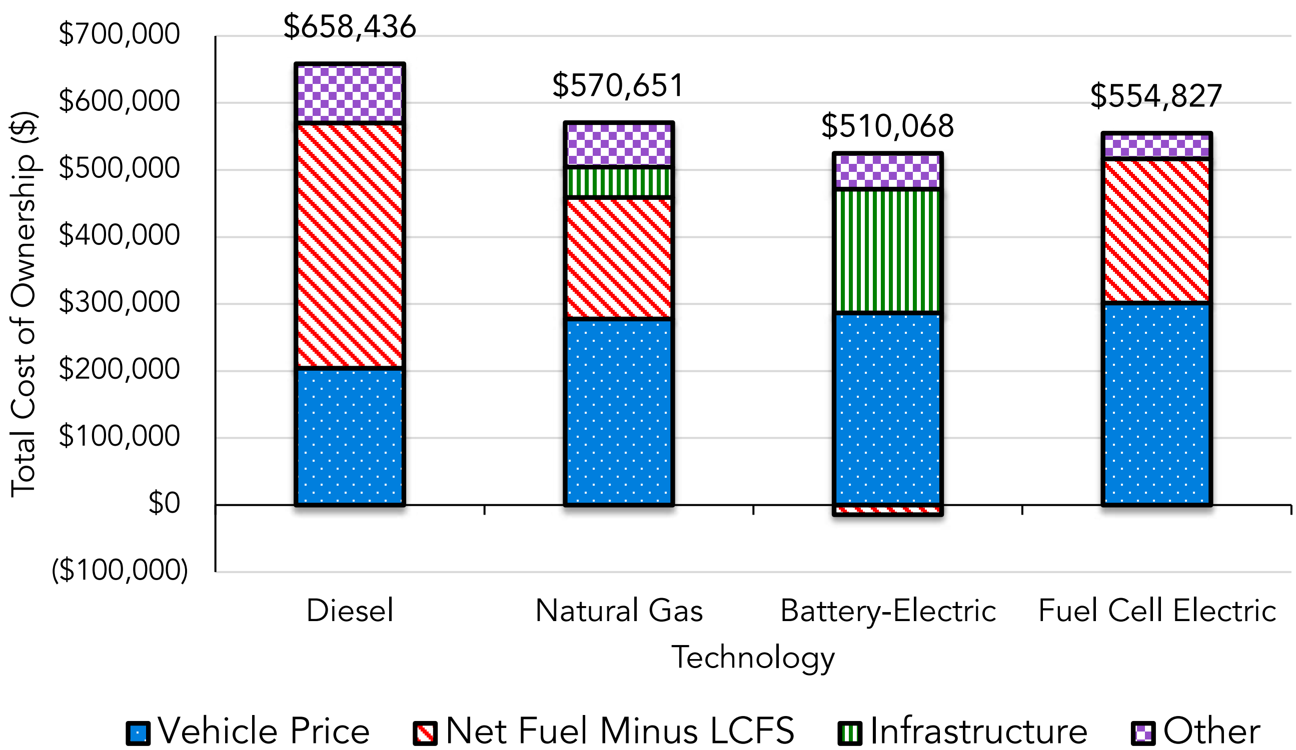

Figure 41: 2025 Day Cab Tractor Cashflow Comparison

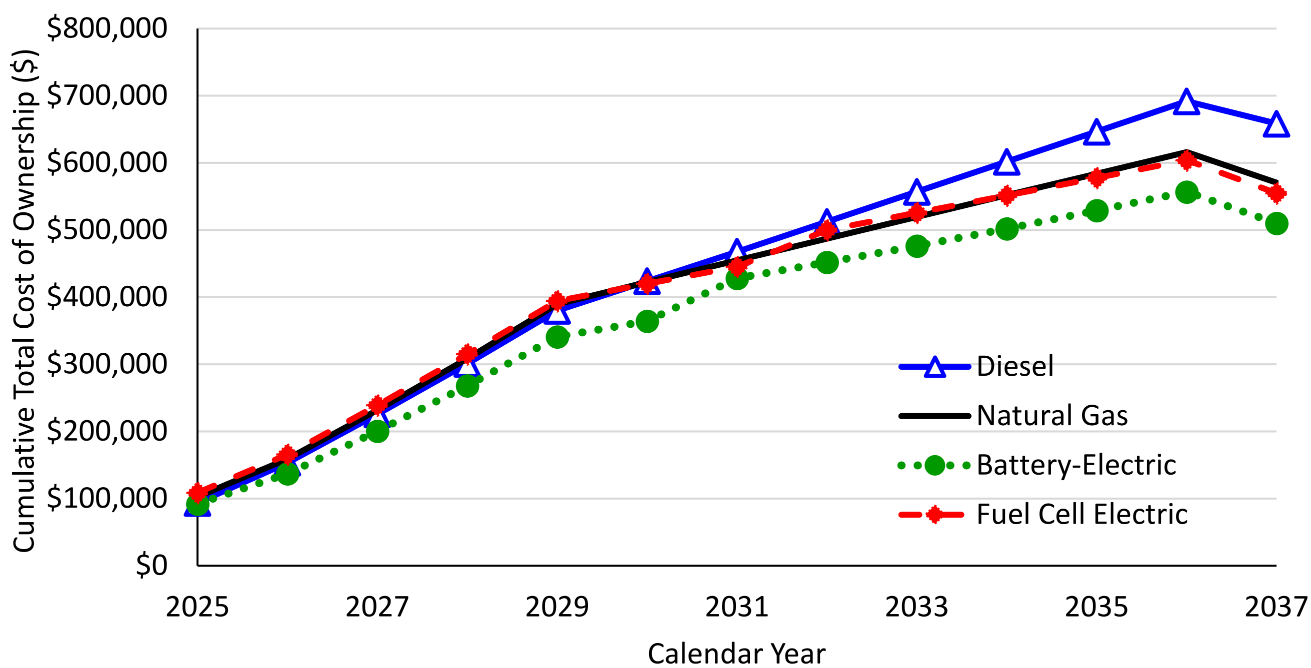

Table 29: 2025 Day Cab Tractor Cost Breakdown

	Diesel	Natural Gas	Battery-Electric	Fuel Cell Electric
Total Miles	599,280	599,280	599,280	599,280
Operating Years	12	12	12	12
Energy Storage	-	-	450 kWh	10 kWh/40 kg H2
Vehicle Power	-	-	350 kW	350 kW/175 kWFC
Vehicle Price	$143,862	$195,607	$201,999	$212,353
Taxes	$28,772	$39,121	$40,400	$42,471
Financing Costs	$31,571	$42,927	$44,329	$46,602
Total Vehicle Cost	$204,205	$277,655	$286,727	$301,425
Fuel Economy	6.7 mpg	6.5 mpg	0.54 mi./kWh	10.9 mi./kg
Unit Fuel Cost	$4.06/gal	$1.98/gal	$0.21/kWh	$5.48/kg
Fuel Cost	$361,069	$181,399	$234,326	$300,201
DEF Consumption	$4,975	$0	$0	$0
LCFS Revenue	$0	$0	-$248,902	-$84,907
Total Fuel Cost	$366,045	$181,399	-$14,576	$215,293
Maintenance Cost	$118,898	$118,898	$89,174	$89,174
Midlife Costs	$0	$0	$40,545	$29,750
Registration Fee	$35,732	$37,733	$16,860	$17,261
Depreciation	-$43,159	-$58,682	-$60,600	-$63,706
Residual Value	-$33,363	-$45,363	-$46,845	-$49,246
Insurance Costs	$10,078	$13,702	$14,150	$14,876
Total Other Costs	$88,186	$66,289	$53,285	$38,108
EVSE Cost	$0	$0	$84,954	$0
Infrastructure Upgrade Cost	$0	$45,309	$99,679	$0
Total Infrastructure Cost	$0	$45,309	$184,633	$0
TOTAL	$658,436	$570,651	$510,068	$554,827
Payback Period vs Diesel (yr)	-	-	8.1	12.1

2030 Day Cab Tractor

Figure 42: 2030 Day Cab Tractor Total Cost of Ownership Comparison

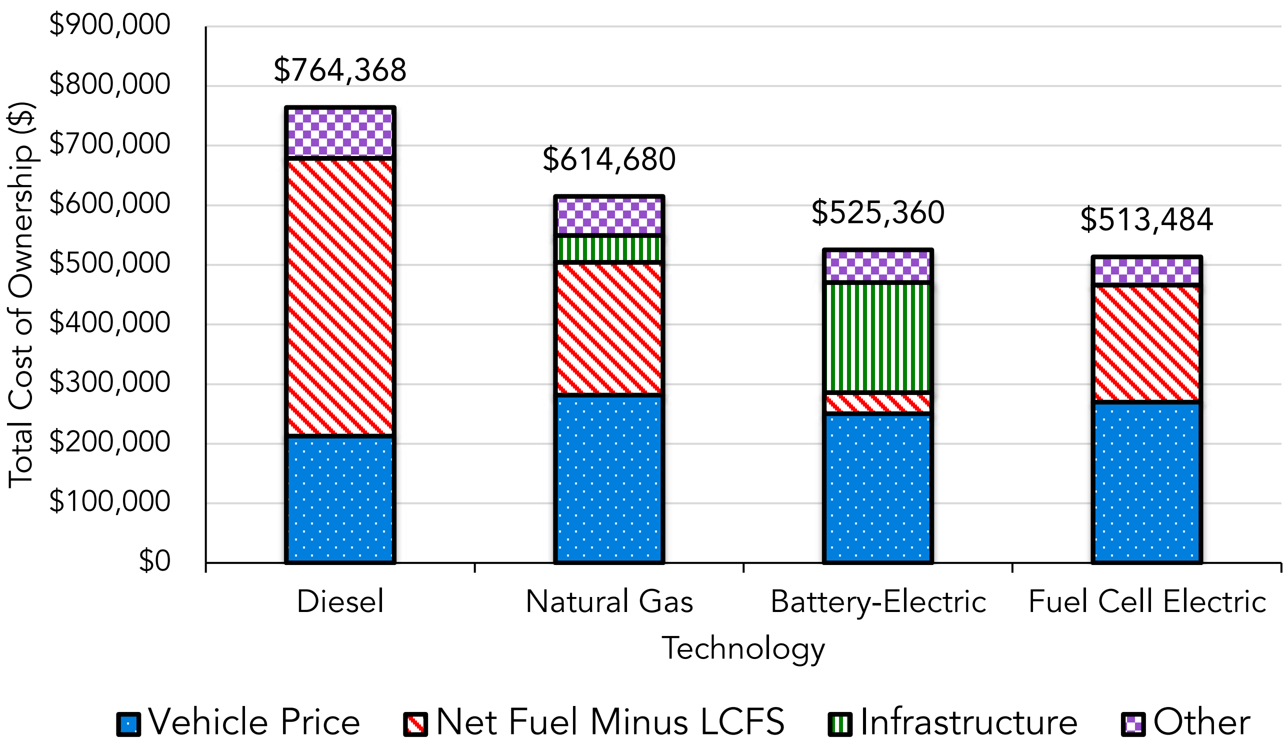

Figure 43: 2030 Day Cab Tractor Cashflow Comparison

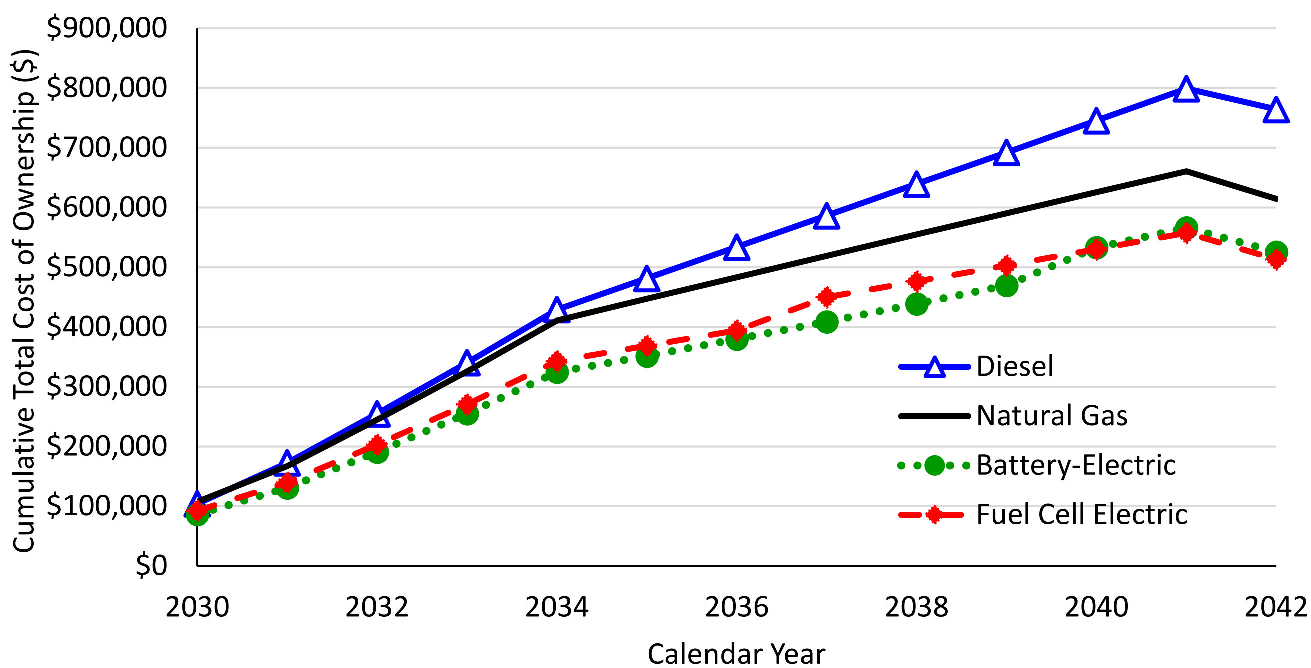

Table 30: 2030 Day Cab Tractor Cost Breakdown

	Diesel	Natural Gas	Battery-Electric	Fuel Cell Electric
Total Miles	599,280	599,280	599,280	599,280
Operating Years	12	12	12	12
Energy Storage	-	-	450 kWh	10 kWh/40 kg H2
Vehicle Power	-	-	350 kW	350 kW/175 kWFC
Vehicle Price	$149,865	$198,263	$176,275	$190,161
Taxes	$29,973	$39,653	$35,255	$38,032
Financing Costs	$32,888	$43,510	$38,684	$41,731
Total Vehicle Cost	$212,726	$281,425	$250,214	$269,924
Fuel Economy	5.5 mpg	5.3 mpg	0.57 mi./kWh	11.6 mi./kg
Unit Fuel Cost	$4.26/gal	$1.95/gal	$0.21/kWh	$5/kg
Fuel Cost	$459,948	$222,782	$223,725	$258,849
DEF Consumption	$6,048	$0	$0	$0
LCFS Revenue	$0	$0	-$188,112	-$62,788
Total Fuel Cost	$465,996	$222,782	$35,613	$196,061
Maintenance Cost	$118,898	$118,898	$89,174	$89,174
Midlife Costs	$0	$0	$31,275	$29,750
Registration Fee	$35,964	$37,836	$15,865	$16,402
Depreciation	-$44,960	-$59,479	-$52,883	-$57,048
Residual Value	-$34,755	-$45,979	-$40,879	-$44,100
Insurance Costs	$10,498	$13,889	$12,348	$13,321
Total Other Costs	$85,646	$65,165	$54,900	$47,499
EVSE Cost	$0	$0	$84,954	$0
Infrastructure Upgrade Cost	$0	$45,309	$99,679	$0
Total Infrastructure Cost	$0	$45,309	$184,633	$0
TOTAL	$764,368	$614,680	$525,360	$513,484
Payback Period vs Diesel (yr)	-	-	5.8	2.3

2035 Day Cab Tractor

Figure 44: 2035 Day Cab Tractor Total Cost of Ownership Comparison

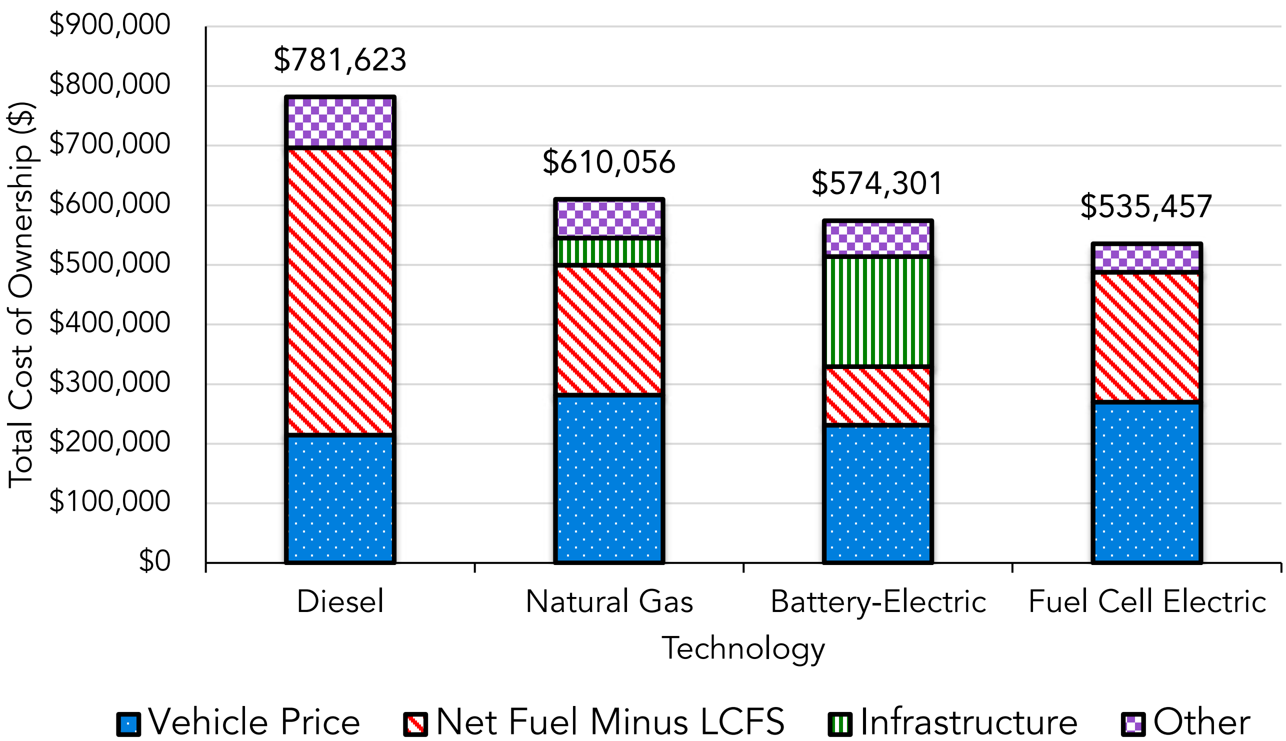

Figure 45: 2035 Day Cab Tractor Cashflow Comparison

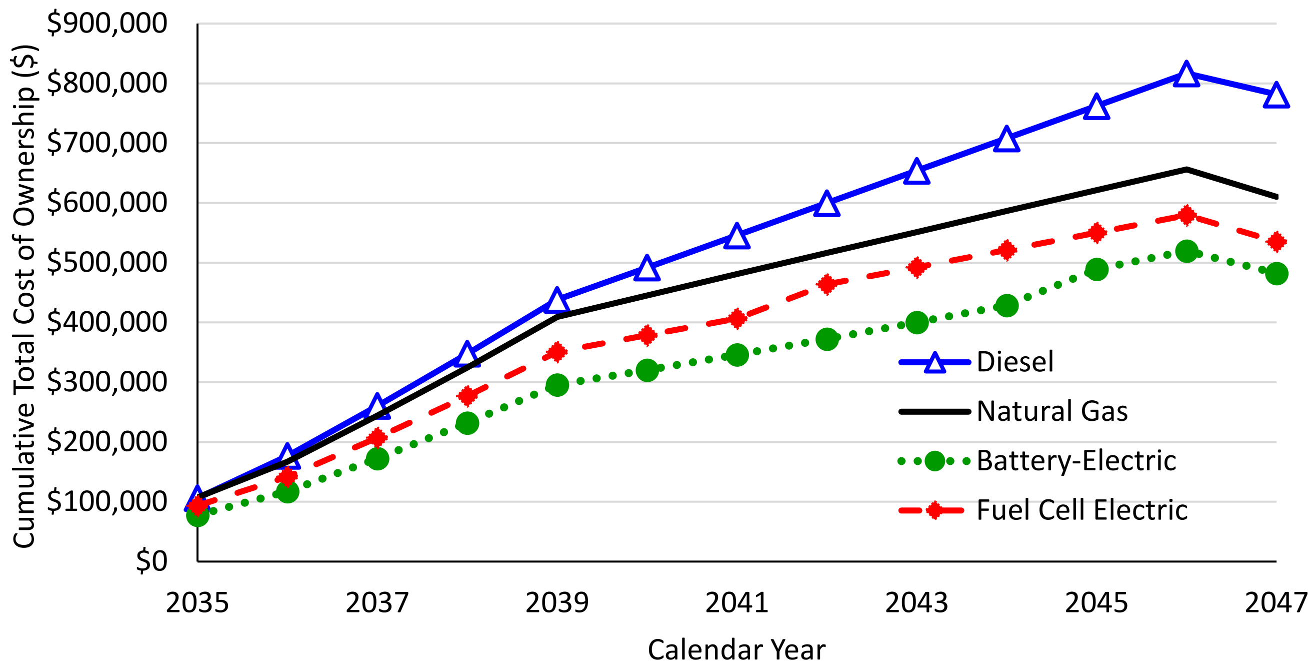

Table 31: 2025 Day Cab Tractor Cost Breakdown

	Diesel	Natural Gas	Battery-Electric	Fuel Cell Electric
Total Miles	599,280	599,280	599,280	599,280
Operating Years	12	12	12	12
Energy Storage	-	-	450 kWh	10 kWh/40 kg H2
Vehicle Power	-	-	350 kW	350 kW/175 kWFC
Vehicle Price	$150,920	$198,457	$162,910	$189,864
Taxes	$30,184	$39,691	$32,582	$37,973
Financing Costs	$33,120	$43,552	$35,751	$41,666
Total Vehicle Cost	$214,224	$281,700	$231,243	$269,503
Fuel Economy	5.5 mpg	5.3 mpg	0.57 mi./kWh	11.6 mi./kg
Average Unit Fuel Cost	$4.41/gal	$1.91/gal	$0.21/kWh	$5/kg
Fuel Cost	$476,151	$217,964	$219,265	$258,849
DEF Consumption	$6,048	$0	$0	$0
LCFS Revenue	$0	$0	-$121,395	-$40,519
Total Fuel Cost	$482,199	$217,964	$97,869	$218,330
Maintenance Cost	$118,898	$118,898	$89,174	$89,174
Midlife Costs	$0	$0	$31,275	$29,750
Registration Fee	$36,005	$37,843	$15,349	$16,391
Depreciation	-$45,276	-$59,537	-$48,873	-$56,959
Residual Value	-$34,999	-$46,024	-$37,780	-$44,031
Insurance Costs	$10,572	$13,902	$11,412	$13,300
Total Other Costs	$85,200	$65,083	$60,556	$47,625
EVSE Cost	$0	$0	$84,954	$0
Infrastructure Upgrade Cost	$0	$45,309	$99,679	$0
Total Infrastructure Cost	$0	$45,309	$184,633	$0
TOTAL	$781,623	$610,056	$574,301	$535,457
Payback Period vs Diesel (yr)	-	-	5.5	2.2

2030 Sleeper Cab Tractor

Figure 46: 2030 Sleeper Cab Tractor Total Cost of Ownership Comparison

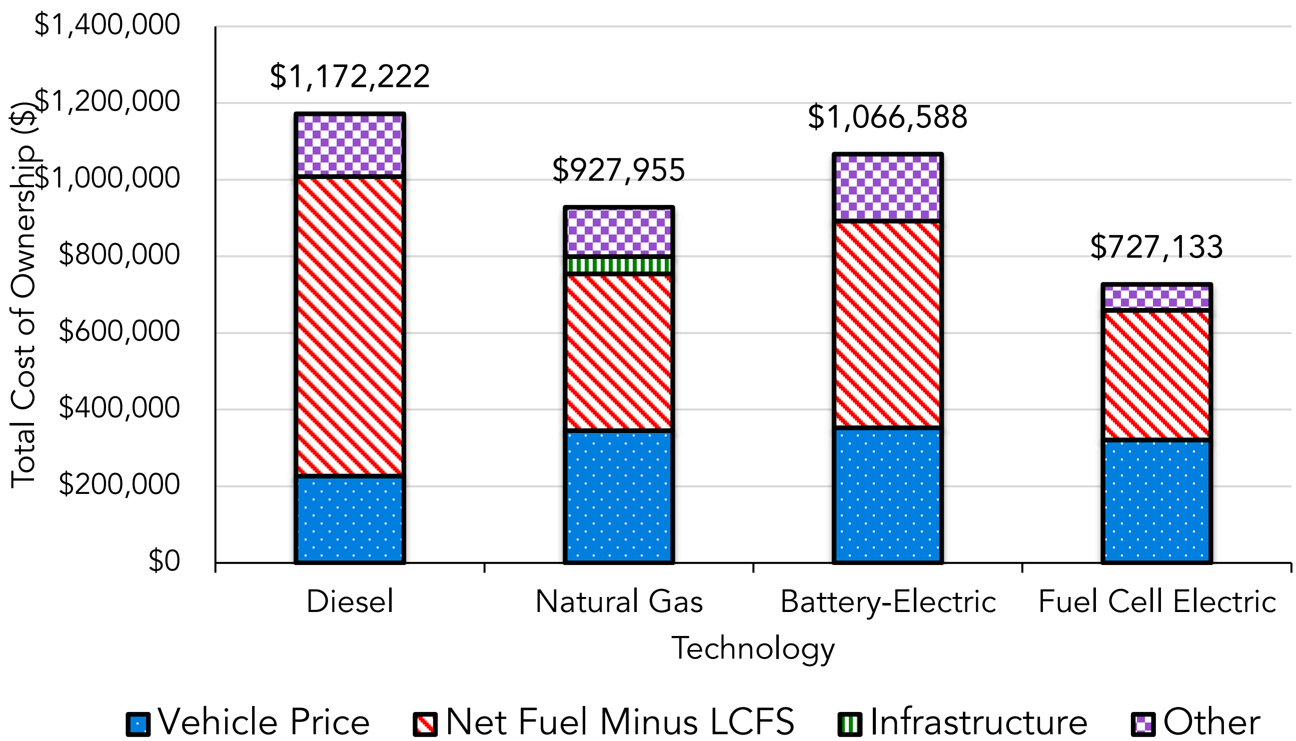

Figure 47: 2030 Sleeper Cab Tractor Cashflow Comparison

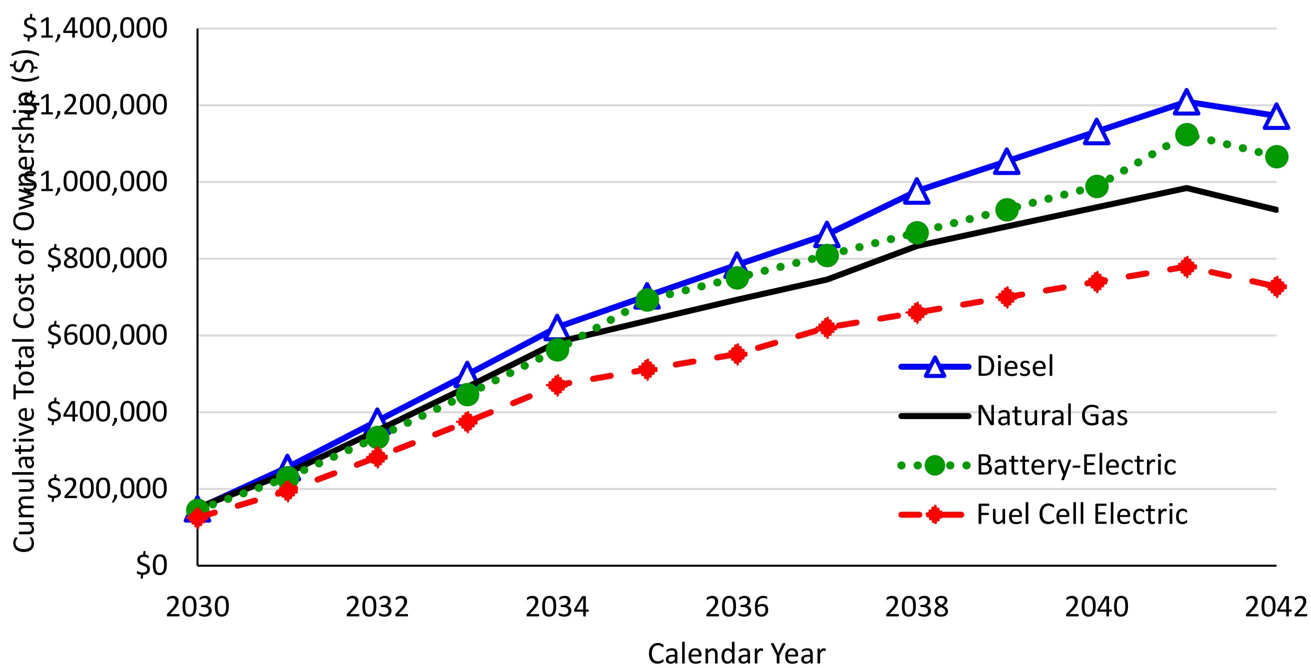

Table 32: 2030 Sleeper Cab Tractor Cost Breakdown

	Diesel	Natural Gas	Battery-Electric	Fuel Cell Electric
Total Miles	1,044,802	1,044,802	1,044,802	1,044,802
Operating Years	12	12	12	12
Energy Storage	-	-	1050 kWh	10 kWh/80 kg H2
Vehicle Power	-	-	350 kW	350 kW/175 kWFC
Vehicle Price	$159,865	$243,263	$248,215	$226,277
Taxes	$31,973	$48,653	$49,643	$45,255
Financing Costs	$35,083	$53,385	$54,472	$49,657
Total Vehicle Cost	$226,921	$345,301	$352,330	$321,190
Fuel Economy	5.8 mpg	5 mpg	0.5 mi./kWh	11.6 mi./kg
Average Unit Fuel Cost	$4.25/gal	$1.95/gal	$0.44/kWh	$5/kg
Fuel Cost	$771,536	$409,042	$923,557	$449,235
DEF Consumption	$10,169	$0	$0	$0
LCFS Revenue	$0	$0	-$383,817	-$110,894
Total Fuel Cost	$781,705	$409,042	$539,740	$338,341
Maintenance Cost	$166,080	$166,080	$124,560	$124,560
Midlife Costs	$35,000	$35,000	$145,950	$29,750
Registration Fee	$36,351	$39,576	$18,648	$17,799
Depreciation	-$47,960	-$72,979	-$74,465	-$67,883
Residual Value	-$37,074	-$56,414	-$57,563	-$52,475
Insurance Costs	$11,199	$17,041	$17,388	$15,851
Total Other Costs	$163,596	$128,304	$174,518	$67,602
EVSE Cost	$0	$0	$0	$0
Infrastructure Upgrade Cost	$0	$45,309	$0	$0
Total Infrastructure Cost	$0	$45,309	$0	$0
TOTAL	$1,172,222	$927,955	$1,066,588	$727,133
Payback Period vs Diesel (yr)	-	-	5.8	2.1

2035 Sleeper Cab Tractor

Figure 48: 2035 Sleeper Cab Tractor Total Cost of Ownership Comparison

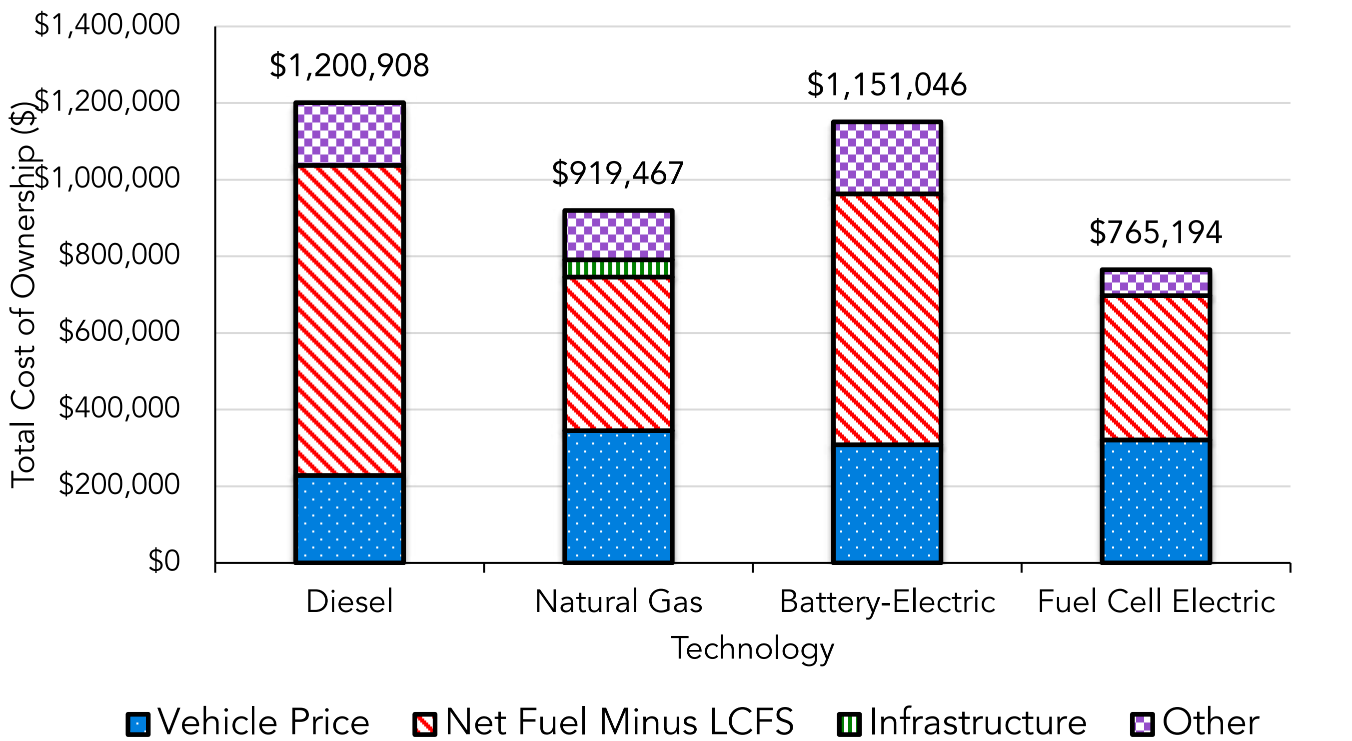

Figure 49: 2035 Sleeper Cab Tractor Cashflow Comparison

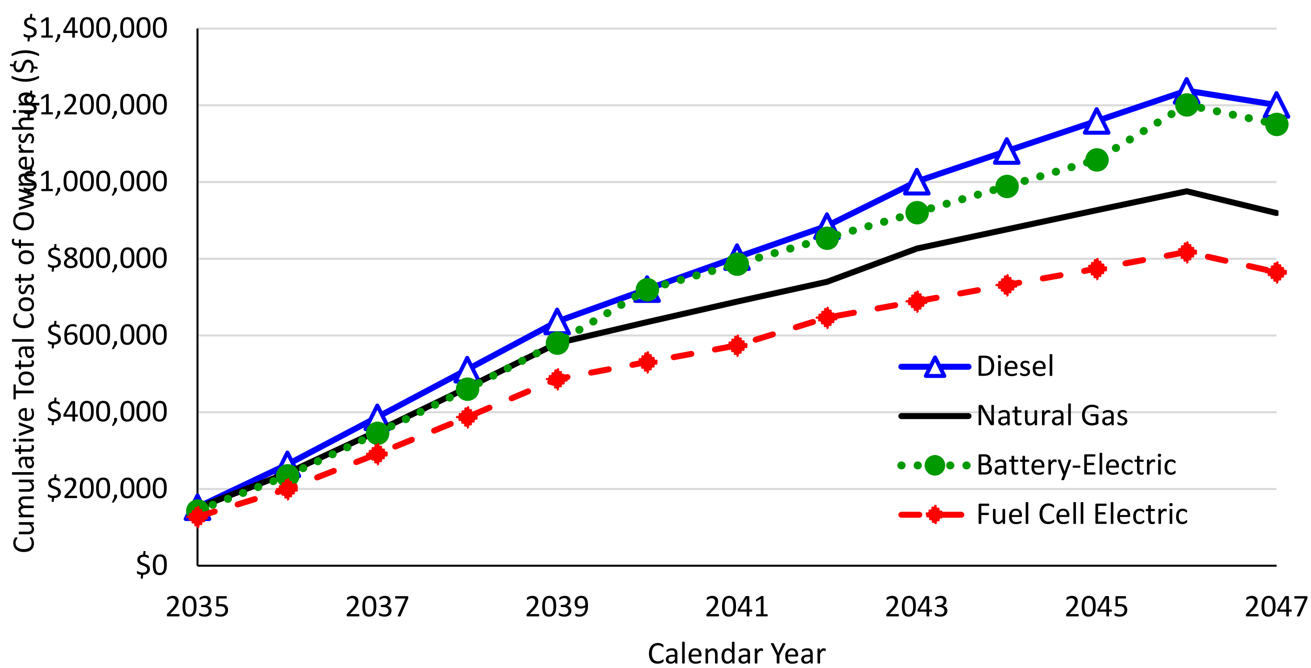

Table 33: 2035 Sleeper Cab Tractor Cost Breakdown

	Diesel	Natural Gas	Battery-Electric	Fuel Cell Electric
Total Miles	1,044,802	1,044,802	1,044,802	1,044,802
Operating Years	12	12	12	12
Energy Storage	-	-	1050 kWh	10 kWh/80 kg H2
Vehicle Power	-	-	350 kW	350 kW/175 kWFC
Vehicle Price	$160,920	$243,457	$217,030	$225,980
Taxes	$32,184	$48,691	$43,406	$45,196
Financing Costs	$35,314	$53,427	$47,628	$49,592
Total Vehicle Cost	$228,418	$345,576	$308,064	$320,769
Fuel Economy	5.8 mpg	5 mpg	0.5 mi./kWh	11.6 mi./kg
Average Unit Fuel Cost	$4.4/gal	$1.91/gal	$0.43/kWh	$5/kg
Fuel Cost	$799,171	$400,361	$906,328	$449,235
DEF Consumption	$10,169	$0	$0	$0
LCFS Revenue	$0	$0	-$251,061	-$72,537
Total Fuel Cost	$809,339	$400,361	$655,267	$376,698
Maintenance Cost	$166,080	$166,080	$124,560	$124,560
Midlife Costs	$35,000	$35,000	$145,950	$29,750
Registration Fee	$36,392	$39,584	$17,442	$17,788
Depreciation	-$48,276	-$73,037	-$65,109	-$67,794
Residual Value	-$37,319	-$56,459	-$50,331	-$52,406
Insurance Costs	$11,273	$17,054	$15,203	$15,830
Total Other Costs	$163,150	$128,222	$187,715	$67,727
EVSE Cost	$0	$0	$0	$0
Infrastructure Upgrade Cost	$0	$45,309	$0	$0
Total Infrastructure Cost	$0	$45,309	$0	$0
TOTAL	$1,200,908	$919,467	$1,151,046	$765,194
Payback Period vs Diesel (yr)	-	-	5.1	2.0

X. Summary of Results

The results of this analysis suggests the following:

- Through a combination of lower fuel costs, decreased maintenance expenses, and revenue from California's LCFS program, ZEVs achieve lower operational costs versus their combustion counterparts. These savings typically outweigh higher upfront costs over the lifetime of the ZEV.
- Costs of batteries and fuel cell components are expected to decline substantially over the next decade and will bring down the incremental capital costs of zero-emission trucks and buses. This will improve their TCO compared to the combustion equivalents. Cost reductions beyond what is modeled are feasible and become more likely with large scale investment into ZEV technologies by manufacturers and fleets.
- Both battery-electric and fuel cell electric vehicles are projected to be cost competitive with combustion-powered vehicles over the course of this analysis. Battery-electric vehicles appear competitive in many categories beginning 2025, while fuel cell electric vehicles appear competitive in either 2025 or 2030 depending on the type of vehicle modeled.
- ZEVs can result in significantly TCO for fleets in specific scenarios. For example, by 2030, a battery-electric Class 5 walk-in van is expected to have a 22 percent lower TCO versus their diesel counterpart resulting in a savings of $47,000 per vehicle. A battery-electric and fuel cell electric day cab operating in a drayage duty cycle is expected to have a 31 and 33 percent lower TCO versus diesel, respectively, resulting in savings of $239,000 and $251,000, respectively.
- Further cost reductions may be feasible as this report does not model potentially reduced costs to fleets as a result of the Advanced Clean Fleets manufacturer ZEV sales requirement. Investments and action by manufacturers can lead to lower costs through out the entire ZEV ecosystem including parts suppliers, infrastructure providers, service technicians, and others.
- Upfront costs are expected to be higher for ZEVs due to additional vehicle and infrastructure expenses. However, by financing these costs and allowing operational savings to accrue, fleets can operate ZEVs with minimal cashflow impact in the initial years. Once the vehicle is paid off, operational savings continue to accrue over time. This allows fleets to purchase and operate ZEVs without seeing the additional costs associated with ZEVs.
- The payback period for ZEVs versus their diesel counterpart varies among vehicles but ranges from five to 10 years in the 2025 analysis. This drops to two to five years in the 2030 and 2035 analyses, indicating that ZEVs are able to recoup their additional costs in a reasonable timeframe.
- Revenue from LCFS credits significantly improves the TCO for battery-electric and fuel cell electric vehicles. LCFS credits can completely offset the cost of charging a battery-electric vehicle and significantly reduce the costs of refueling fuel cell electric vehicles.
- Although they are not included in this analysis, grants, incentives, and utility infrastructure programs can further reduce the upfront costs to get fleet owners to act early.